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ICE ACCRETION ON AIRCRAFT IN WARM-FRONT CONDITIONS

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Introduction.—Wexler[1] has deduced that only the ice phase exists at temperatures below about $-5°$C. in stratiform clouds from which widespread precipitation of fairly uniform intensity is falling. His method of reaching this conclusion was rather indirect and it seems worth while to derive directly an approximate criterion for the maintenance of a relative humidity of 100 per cent. with respect to liquid water in ascending air which contains ice particles. If this condition is maintained we may expect condensation into liquid water drops to occur and hence the existence of potential icing conditions. The maintenance of 100 per cent. relative humidity with respect to liquid water depends upon the rate of ascent of the air being sufficiently fast for water vapour, surplus to that required for saturation with respect to liquid water, becoming available at a rate equal to the rate of deposition of water onto the ice crystals in the saturated atmosphere.

The rate of release of water vapour in ascending air.—Let us denote the saturation density (with respect to liquid water) of water vapour by ρ_w. As the air ascends the temperature falls and ρ_w decreases. In a particular parcel of air the rate at which water vapour becomes surplus to the amount required for saturation is $-d\rho_w/dt$. According to Dalton's law we may put

$$\rho_w = \frac{M}{R}\frac{p_w}{\theta},$$

where M is the molecular weight of water (18), R the gas constant ($8{\cdot}31\times10^7$ erg deg.$^{-1}$ mol.$^{-1}$), θ the temperature (degrees absolute), and p_w the saturation vapour pressure (dynes cm.$^{-2}$).

and so
$$\frac{d\rho_w}{dt} = \frac{M}{R\theta}\left(\frac{\partial p_w}{\partial\theta} - \frac{p_w}{\theta}\right)\frac{d\theta}{dt}.$$

If the air is ascending at a rate V(cm. sec.$^{-1}$) and the lapse rate in the cloud is Γ_s(°C. cm.$^{-1}$) we can replace $d\theta/dt$ by $-V\Gamma_s$ and so get

$$\frac{d\rho_w}{dt} = -\frac{M}{R\theta}\left(\frac{\partial p_w}{\partial\theta} - \frac{p_w}{\theta}\right)V\Gamma_s \quad \ldots\ldots (1)$$

This is the rate at which water vapour is available for deposition on the ice particles if saturation with respect to liquid water is to be maintained.

Rate of deposition of water vapour on ice particles.—If an ice particle exists in an atmosphere in which the vapour pressure is not equal to the vapour

pressure at the surface of the particle, vapour will be conducted to or from the particles by gaseous diffusion. Sublimation or evaporation will occur and, owing to the release or absorption of latent heat, the temperature of the particle will differ from the ambient temperature. The evaporation or growth of the particle in a stationary atmosphere is a problem in gaseous diffusion, the solution to which has been given by Jeffreys[2]. Because the particle temperature differs from the ambient temperature, heat will be conducted to or from the particle by a process analagous to the diffusion of vapour. If a steady state is reached in which the temperature of the particle neither rises nor falls, the sum of the heat conducted to the particle and the heat released by sublimation must be zero. We can describe these processes as follows. Jeffreys's solution[2] for the rate of growth of the particle is

$$\frac{dm}{dt} = 4\pi DCG\,(\rho_o - \rho_s) \qquad \ldots\ldots (2)$$

and the analogous equation for heat conduction is

$$\frac{dH}{dt} = 4\pi kCG\,(\theta_e - \theta_s)\,. \qquad \ldots\ldots (3)$$

The equation representing the steady state is

$$\frac{dH}{dt} + \frac{\lambda}{M}\frac{dm}{dt} = 0\,, \qquad \ldots\ldots (4)$$

where

m = mass of ice particle (gm.)
D = coefficient of diffusion of water vapour in air (cm.^{2} sec.$^{-1}$)
C = electrostatic capacity of a conductor of the same shape as the ice particle
G = coefficient introduced to take account of relative motion between the particle and the atmosphere
ρ_o = ambient vapour density (gm. cm.$^{-3}$)
ρ_s = vapour density at particle surface (gm. cm.$^{-3}$)
H = heat content of particle above some arbitrary level (cal.)
k = thermal conductivity of air (cal. cm.$^{-1}$ sec.$^{-1}$ deg.$^{-1}$)
θ_e = ambient temperature (°C.)
θ_s = particle surface temperature (°C.)
λ = latent heat of vaporization of ice (cal. mol.$^{-1}$)
σ = density of ice (gm. cm.$^{-3}$).

Using Dalton's law to replace vapour densities by vapour pressures and assuming the particles are spherical with an equivalent radius a (see Appendix) so that we can write $m = 4\pi a^3\sigma/3$ and $C = a$ we eliminate dH/dt from equations (2)–(4) and, after a little manipulation, get

$$\Delta\theta = \frac{\lambda\sigma}{kGM}\,a\,\frac{da}{dt} \qquad \ldots\ldots (5)$$

$$p_o - p_s = \frac{R\theta\sigma}{DGM}\,a\,\frac{da}{dt} \qquad \ldots\ldots (6)$$

where $\Delta\theta$ is the excess of particle temperature over ambient temperature. Equations (5) and (6) represent the growth of the (spherical) ice particle at a temperature $\theta + \Delta\theta$ in an environment in which the temperature is θ and the vapour pressure is p_o. The vapour pressure at the particle surface is p_s. We are

here interested in the case in which $p_s = p_w$ and, provided $\Delta\theta$ is not too large, we may put

$$p_s = p_i + \Delta\theta \frac{\partial p_i}{\partial \theta}$$

where p_i is the saturation vapour pressure over ice at temperature θ. We then easily obtain from equations (5) and (6)

$$a\frac{da}{dt} = \frac{GMDk\,(p_w - p_i)}{\sigma(R\theta k + D\lambda\,\partial p_i/\partial\theta)} \quad \ldots\ldots (7)$$

to represent the rate of growth of a single particle.

Condition for maintenance of water saturation.—In order that water saturation may be just maintained we must have

$$4\pi n\sigma a^2 \frac{da}{dt} = -\frac{d\rho w}{dt},$$

where n is the number of ice particles per cubic centimetre. Substituting for da/dt and $d\rho_w/dt$ from equations (7) and (1) respectively we obtain

$$V = B\frac{Gan}{\Gamma_s}, \quad \ldots\ldots (8)$$

where

$$B = \frac{4\pi kDR\theta\,(p_w - p_i)}{(\partial p_w/\partial\theta - p_w/\theta)\,(R\theta k + D\lambda\,\partial p_i/\partial\theta)}. \quad \ldots\ldots (9)$$

In order to assess the minimum value of V necessary to maintain liquid water in the cloud we must evaluate the five variables of which V is a function.

Evaluation of B.—The quantity we have denoted by B is a function of temperature. Inserting appropriate numerical values for various parameters (c.g.s. units) we find the following values.

θ(°A.)	273	268	263	258	253	248	243
B	0	1·0	2·2	3·3	4·3	5·1	5·7

Evaluation of Γ_s.—The temperature lapse rate in the cloud is a function of height and temperature but a reasonable approximation to the saturated lapse rate is given by taking $\Gamma_s = 7 \times 10^{-5}$ °C. cm.$^{-1}$.

Evaluation of a.—The evaluation of a, the radius of the equivalent spherical ice particle, is somewhat more difficult. As a preliminary step it is useful to consider the rate of growth indicated by equation (7) and with the assumption that G is unity. If S is the surface area of the ice sphere

$$\frac{dS}{dt} = 8\pi a\frac{da}{dt}$$

$$= \frac{8\pi GMDk\,(p_w - p_i)}{\sigma(R\theta k + D\lambda\partial p_i/\partial\theta)}.$$

Thus dS/dt is a function only of temperature. Inserting appropriate values for the parameters involved and putting $\sigma = 0{\cdot}9$ and $G = 1$ we get

θ	268	263	258	253	248	243
dS/dt	$5{\cdot}6\times10^{-7}$	$8{\cdot}5\times10^{-7}$	$9{\cdot}2\times10^{-7}$	$8{\cdot}4\times10^{-7}$	$7{\cdot}0\times10^{-7}$	$5{\cdot}2\times10^{-7}$

in c.g.s. units. The variation with temperature is thus small and to a close approximation we can put $dS/dt = 8 \times 10^{-7}$ and $S = 8 \times 10^{-7}t$ to give a

reasonable approximation to the size of the particle t sec. after it is first formed in an atmosphere saturated with respect to liquid water. From this formula we easily obtain the following values for the radius of the equivalent spherical ice particle

t (sec.)	10	100	1,000	10,000
a (μ)	8	25	80	250

The radius varies as the square root of the time and it is apparent that a reaches a value between 50 and 100 μ within minutes but that hours are necessary for the particle to grow to significantly greater sizes. We shall see below that G is of the order $2 \cdot 3$ so that the assumption of unity for G has led to an underestimation of a by a factor of less than $1 \cdot 5$. Weickmann[3] has provided a number of photographs of ice crystals caught in cirrus cloud. Many of these crystals were in the form of plates or prisms and photographs of 17 were measured and the radius of the sphere of similar surface area computed assuming the prisms to be cylinders and the plates to be discs. For the prisms the resulting value of a was about 80 μ at 233°A. and about 160 μ at 263°A. The plates occurred only at the higher temperatures of course and gave a mean value of about 250 μ for a at 263°A. These values are in agreement with the values to be expected (as regards order of magnitude) from consideration of the rate of growth and we may conclude that a is likely to be between 50 μ and 300 μ.

Evaluation of G.—The best known formula for G is probably that of Frossling[4] who suggested

$$G = 1 + 0 \cdot 23(R_e)^{\frac{1}{2}},$$

where R_e is the Reynolds number of the falling particle. Frossling's result[4] was based upon the evaporation of spherical drops of water. The present writer[5], from a consideration of work including heat transfer as well as vapour transfer, has suggested

$$G = 1 + 0 \cdot 14(R_e)^{0 \cdot 6}.$$

In view of the accuracy with which we can work in the present problem the difference is not significant. For both formulae we must evaluate R_e.

Nakaya[6] quotes the average size of plate crystals as $0 \cdot 8$ mm. and prism crystals as $0 \cdot 5$ mm. The terminal velocities of crystals are not known in detail, but on the basis of the terminal velocities quoted by Nakaya for other types of crystal it seems likely that they are less than 60 cm. sec.$^{-1}$ for the plate and 100 cm. sec.$^{-1}$ for the prism. Taking the kinematic viscosity of air as $0 \cdot 12$ c.g.s. units these figures lead to values of 40 and 42 for the Reynolds number for plate and prism respectively. Whichever formula is used for G we then get a value of about $2 \cdot 3$. The values of a tabulated as a function of time in the preceding section were based upon a value of unity for G. The actual value varies with the crystal size but since $G \simeq 2 \cdot 3$ for the average crystal and since a varies as $\sqrt{G}$ the factor by which the tabulated values are in error is probably less than $1 \cdot 5$.

Evaluation of n.—This is the most difficult parameter to assess. The work of Findeisen and Shulz[7] suggests that the initial formation of ice crystals in rising air may be at the rate of about one per cubic metre at 263°A. and 1 per litre at 243°A. If this is so we should put $n = 10^{-6}$ at 263°A. and $n = 10^{-3}$ at 243°A. Subsequently of course more crystals may be produced by the splintering process and this may be the dominant factor in the later stages of the life of the cloud.

Minimum up-draught to maintain liquid water.—We have seen, equation (8) that,

$$V = B\frac{Gan}{\Gamma_s}.$$

Putting in the values

θ	B	G	a	n	Γ_s
			c.g.s. units		
263	2·2	2·3	200×10^{-4}	10^{-6}	7×10^{-5}
243	5·7	2·3	100×10^{-4}	10^{-3}	7×10^{-5}

we get $1\cdot4\times10^{-3}$ cm. sec.$^{-1}$ and 1·9 cm. sec.$^{-1}$ as the minimum up-draught necessary to maintain a liquid water content at 263°A. and 243°A. respectively. These values of V may occur in association with warm fronts and we may accordingly expect supercooled liquid water drops to occur in the initial stages of such a frontal system and to be more numerous with the greater values of V, i.e. in the more vigorous fronts. It also follows that convective clouds with much greater values of V, will be far more likely to give icing conditions.

In the later stages of the life of the warm-front system we may assume that ice crystals which have formed at the higher levels have fallen to lower levels and that n has been greatly increased by splintering. It is difficult to assess the value of n in these conditions but it seems reasonable to assume that at the lower levels it is not less than the number of raindrops per unit volume nearer the ground. If we assume a rate of rainfall of 2·5 mm. hr.$^{-1}$ some earlier calculations[8] suggest that the number of raindrops is of the order of 3,000 m.$^{-3}$. If we use this value for n at 263°A. we get a critical up-draught of about 4 cm. sec.$^{-1}$. Bannon[9] has computed up-currents in selected cases of rainfall associated with depressions and has obtained values of 10–20 cm. sec.$^{-1}$ with rates of rainfall of about 2·5 mm. hr.$^{-1}$.

Conclusions.—There is considerable uncertainty about the present calculations of the critical up-draught but the significance of the values obtained lies not in the precise speeds but in the fact that, in normal conditions, they can be of the same order as the up-draughts associated with warm fronts. Significant variations in n must occur and it must often happen that the actual up-draught is very near the critical value, sometimes smaller and sometimes greater. With variations in n and in the actual up-draught it is easy to visualize the out-of-balance being in opposite directions at places separated by only a few miles or at the same place during comparatively short periods of time. We should thus expect apparently contradictory icing reports from aircraft flying in apparently similar warm-front conditions. This does not help much with forecasting problems but it may be useful to note two implications. A vigorous up-draught is favourable for icing but the icing risk should have diminished when the rate of rainfall becomes high since, according to the Bergeron-Findeisen theory, this implies a large number of ice crystals.

Appendix

Equivalent spherical ice crystal

Ice crystals may be of various shapes, the particular shape depending upon the conditions of growth. The treatment of the rate of growth of an ice crystal by deposition is facilitated if we can assume the crystal to be spherical. Since

evaporation and sublimation are surface phenomena one might speculate that the total rate of deposition on to a non-spherical crystal is very similar to the total rate of deposition on to a spherical crystal having the same surface area. We shall show that for two particular shapes this is a reasonable assumption.

Jeffreys[2] has given the solution to the equation, representing the diffusion of water to or from a droplet or crystal, in a form in which the shape of the droplet or crystal is represented by C, the electrostatic capacity. Thus two crystals of different shapes will increase in mass, in the same ambient conditions, at rates which are proportional to their respective electrostatic capacities. The electrostatic capacity of a sphere is numerically equal to its radius. The electrostatic capacity and surface area of a spheroid generated by an ellipse of eccentricity e are

	Prolate spheroid	Oblate spheroid
Axis of rotation...	Major	Minor
Surface area ...	$2\pi a^2(1-e^2)\left\{1+\dfrac{\sin^{-1}e}{e\sqrt{(1-e^2)}}\right\}$	$2\pi a^2\left\{1+\dfrac{1-e^2}{2e}\log_e\dfrac{1+e}{1-e}\right\}$
Electrostatic capacity ...	$2ae/\log_e\dfrac{1+e}{1-e}$	$ae/\sin^{-1}e$

In these expressions $2a$ is the major axis of the generating ellipse and the minor axis, $2b$, is given by $b^2 = a^2(1-e^2)$.

From these formulae it is a matter of simple arithmetic to compute the ratio of the capacity of a sphere, having the same surface area as the spheroid, to the capacity of the spheroid for various values of the eccentricity e. Some results of such calculations, together with the corresponding values of the ratio of the major to the minor axis of the generating ellipse, are shown in Table I.

TABLE I—RATIO OF CAPACITY OF EQUIVALENT SPHERE TO CAPACITY OF SPHEROID

Eccentricity e	Ratio of axes $\frac{a}{b}=\frac{1}{\sqrt{(1-e^2)}}$	Ratio of capacity of equivalent sphere to capacity of spheroid Prolate	Oblate
0·9	2·3	0·99	1·006
0·95	3·2	0·97	1·016
0·99	7·1	0·89	1·049
0·995	10·0	0·85	1·061
0·999	22·3	0·71	1·084
0·9999	70·7	0·52	1·101

As e increases to unity, the capacity ratio for the prolate spheroid diminishes to zero and for the oblate spheroid increases to 1·11 $(=\pi/2\sqrt{2})$. It is thus clear that an equivalent sphere can be treated instead of an oblate spheroid with an error not exceeding 11 per cent. and instead of a prolate spheroid with an error which does not exceed 50 per cent. provided the major axis is not more than 70 times the minor axis. It is also reasonable to assume that an oblate spheroid, with e nearly unity, is a good approximation to a flat plate and that a prolate spheroid is a good approximation to a needle or column. For the purpose of calculating evaporation or sublimation we can accordingly replace ice crystals of these three shapes by spheres of equal area.

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A DIRECT-READING GEOSTROPHIC WIND SCALE

By L. S. MATTHEWS

Introduction.—The geostrophic wind scale described below incorporates corrections for the variation of the Coriolis acceleration and of chart scale with latitude. The instrument may be adapted for use on any orthomorphic chart whose scale at a point is a function of latitude alone.

Directions are given for the construction of scales for use on Mercator's conical orthomorphic and polar stereographic projections, which are those adopted for meteorological use[1].

The advantages of this instrument are:

(i) It may be used in very low or high latitudes with equal facility.

(ii) The geostrophic wind speed is obtained directly, no further correction being required.

(iii) A single instrument may be graduated for use on more than one chart projection.

So far as can be ascertained from the available literature[2-7], no single geostrophic scale yet proposed incorporates all these advantages.

Theory and description of the scale.—The equation for geostrophic motion is

$$2\,\omega\,v\sin\phi = -\frac{dG}{dn}, \qquad \ldots\ldots (1)$$

where v is geostrophic wind, ω the earth's angular velocity, ϕ the latitude, dG the geopotential interval between successive contours of an isobaric surface and dn is the corresponding horizontal interval measured along the common normal to the contours. Equation (1) applies to a wind in any direction, the wind being parallel to the contours.

On a map drawn to an orthomorphic projection the angles are conserved, and the scale relation between distances on the map and on the earth is a point function varying over the map but independent of the direction in which the distance is measured. Thus, considering only projections in which the scale is a function of latitude alone, we may write

$$ds = f(\phi)\,dn, \qquad \ldots\ldots (2)$$

where ds and dn are corresponding small distances on the map and on the earth respectively, and $f(\phi)$ is the scale value at latitude ϕ; dG is fixed as the conventional geopotential interval between successive contours.

Equation (1) may be written as

$$v = \frac{k f(\phi)}{(\sin \phi).ds} \quad \ldots\ldots (3)$$

where

$$k = \frac{dG}{2\omega}.$$

A scale may be constructed as shown in Fig. 1. A rotating cursor C fixed at O moves over a graduated scale S which is a circle of centre O. The angle θ between the cursor and a fixed initial line OX is a function, to be determined, of the latitude ϕ at which the scale is to be used. The line OX is graduated inversely as the speed v, so that the distance from O of the projection N of a point P on the cursor is given by

$$\mathrm{ON} = \frac{A}{v}, \quad \ldots\ldots (4)$$

where A is a numerical constant and v is the geostrophic wind speed corresponding to the contour spacing PN, in the latitude ϕ to which the cursor is set on scale S. Eliminating v from equations (3) and (4)

$$\frac{A \sin \phi}{k f(\phi)} = \frac{\mathrm{ON}}{ds} = \cot \theta. \quad \ldots\ldots (5)$$

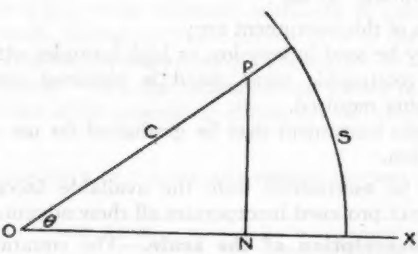

FIG. 1

The scale S may now be graduated in terms of ϕ by using the relation

$$\cot \theta = \frac{A \sin \phi}{k f(\phi)}. \quad \ldots\ldots (6)$$

The formulae[8] for chart scale $f(\phi)$ are as follows:

(i) Mercator's projection with standard parallels 22½°N. and 22½°S.

$$f(\phi) = \sec \phi \cos 22\tfrac{1}{2}°. \quad \ldots\ldots (7)$$

(ii) Conical orthomorphic projection with standard parallels 30° and 60°.

$$f(\phi) = \frac{1 \cdot 283\, [\tan \tfrac{1}{2}(90° - \phi)]^{0 \cdot 7157}}{\cos \phi}. \quad \ldots\ldots (8)$$

(iii) Polar stereographic projection

$$f(\phi) = \frac{2 \tan (45° - \tfrac{1}{2}\phi)}{\cos \phi}. \quad \ldots\ldots (9)$$

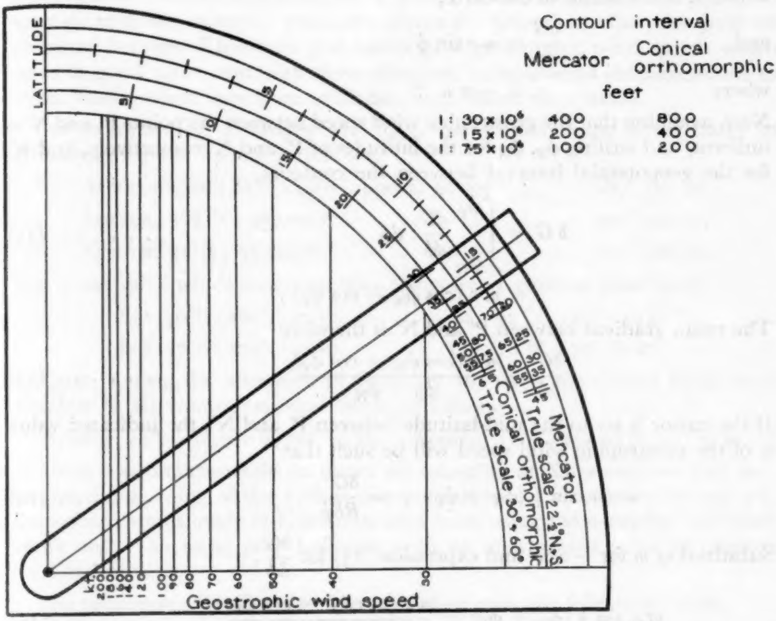

FIG. 2—SCALE GRADUATED FOR USE ON MERCATOR'S AND CONICAL ORTHOMORPHIC PROJECTIONS

Fig. 2 shows a scale graduated for use on Mercator's projection, with standard parallels 22½°N. and 22½°S., and on the conical orthomorphic projection with standard parallels 30° and 60°.

Directions for using the scale.—First draw on the map the common normal P′N′ to two consecutive contours of the isobaric surface at the desired position. Set the cursor to the latitude on scale S, and place the scale on the map, adjusting its position so that N′ lies on OX, P′N′ is perpendicular to OX, and P′ lies on the cursor line. Then PN coincides with P′N′, and the geostrophic wind speed may be read off the scale OX at the point N, since

$$\mathrm{ON} = \mathrm{PN}\cot\theta \,. \qquad \ldots\ldots \quad (10)$$

With a little practice the scale may be used without actually drawing the line P′N′.

When the contours are orientated north to south, P′ and N′ lie in the same latitude and there is no difficulty in setting the cursor to the correct latitude. When the contours are orientated in any other direction, however, P′ and N′ lie in different latitudes. It can be shown that the best latitude setting in such cases is the mid-latitude between the points P′ and N′.

Considering the extreme case when the contours are orientated exactly west to east, equation (1) may be written

$$2\,\omega v \sin\phi = -\frac{dG}{R\,d\phi}\,, \qquad \ldots\ldots \quad (11)$$

where R is the radius of the earth,

and $$\frac{dG}{d\phi} = m\,v \sin\phi\,,$$

where $$m = -\,2\,\omega\,R.$$

Now, assuming that the geostrophic wind speed between the points P′ and N′ is uniform, and writing ϕ_P, ϕ_N for the latitudes of P′ and N′ respectively, and δG for the geopotential interval between the contours,

$$\delta\,G = \int_{\phi_N}^{\phi_P} \frac{dG}{d\phi}\,.\,d\phi \qquad \ldots\ldots (12)$$

$$= m\,v\,(\cos\phi_N - \cos\phi_P)\,.$$

The mean gradient between P′ and N′ is therefore

$$\frac{\delta G}{\delta\phi} = \frac{m\,v\,(\cos\phi_N - \cos\phi_P)}{\phi_P - \phi_N}\,. \qquad \ldots\ldots (13)$$

If the cursor is set to the mid-latitude between P′ and N′, the indicated value v_i of the geostrophic wind speed will be such that

$$2\,\omega\,v_i \sin\tfrac{1}{2}\,(\phi_N + \phi_P) = -\,\frac{\delta G}{R\delta\phi}\,. \qquad \ldots\ldots (14)$$

Substituting m for $-2\omega R$ and expression (13) for $\frac{\delta G}{\delta\phi}$,

$$m\,v_i \sin\tfrac{1}{2}\,(\phi_N + \phi_P) = \frac{m\,v\,(\cos\phi_N - \cos\phi_P)}{\phi_P - \phi_N}\,. \qquad \ldots\ldots (15)$$

Hence $$\frac{v_i}{v} = \frac{\cos\phi_N - \cos\phi_P}{(\phi_P - \phi_N)\sin\tfrac{1}{2}\,(\phi_N + \phi_P)}\,.$$

The expression on the right-hand side of this equation does not differ appreciably from 1 for any value of ϕ_N and for values of $(\phi_P - \phi_N)$ up to at least 10°. This is true even when $\phi_N = 0$.

It follows that if the cursor is set to the mid-latitude between the points P′ and N′, the geostrophic wind speed obtained by the use of the scale approximates very closely to the true value: the only condition is that the wind speed between the contours should be uniform, or nearly so. This condition is fulfilled in practice if the contours are drawn at sufficiently close intervals.

Conversely, the scale may be used to determine the correct spacing of the contours when the wind speed only is known. This property is of particular value when constructing charts covering regions where observations of upper air temperatures and pressures are sparse, as in many parts of Africa and over the oceans.

Practical examples of the use of the scale.—The scale has proved its usefulness at Khartoum in the construction and interpretation of pressure-level contour charts in connexion with Comet flights. The nearest available upper air soundings were those made at Khartoum, Aden, Nairobi, Nicosia, Benina and Cairo. It was therefore difficult to draw accurately the contours between Khartoum and the Mediterranean coast. It was found however that, if the contours near Khartoum and Cairo (or Nicosia, when the Cairo

observations were not available), were spaced on the assumption that the winds were geostrophic, at any rate at levels above the 500-mb. surface, the gradient obtained between Khartoum and Cairo gave geostrophic wind speeds which were in good agreement with those observed. Upper-wind determinations at Wadi Halfa, when they were available, were found very useful.

For example, on February 11, 1953, the Comet flying from Cairo to Khartoum reported winds as follows:

At top of climb from Cairo (approx. 30,000 ft.)...	280° 130 kt.
Approx. $26\frac{1}{2}$°N., 33,000 ft.	272° 120 kt.
Approx. 21°N., 35,000 ft.	284° 103 kt.

The geostrophic winds measured from the 200-mb. contour chart were:

Lat. 30°N. 280° 120 kt.	Lat. 22°N. 270° 110 kt.
Lat. 27°N. 270° 120 kt.	Lat. 18°N. 270° 85 kt.

Again, during the afternoon of February 16, 1953, the Comet flying from Entebbe to Khartoum reported winds as follows:

Approx. $7\frac{1}{2}$°N. 34,000 ft. 10° 77 kt. Approx. 12°N. 35,000 ft. 28° 70 kt.

There was unfortunately no upper air sounding at Khartoum on that day, but on the morning of the 17th it was possible to draw contours for 200 mb. from observations made at Khartoum and Aden using radio-sondes, and Wadi Halfa and Wau using pilot balloons, with an interpolated value of pressure level at Nairobi.

The geostrophic winds scaled from this chart gave the following values:

Lat. $7\frac{1}{2}$° N. 20° 80 kt. Lat. 12°N. 20° 65 kt.

The extrapolations in space and time are certainly greater than one would wish, but the agreement between the observed and scaled winds is striking and encourages the hope that at least at these high levels the winds may be found to agree closely with the geostrophic winds, even in very low latitudes.

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NOCTURNAL WIND AT THORNEY ISLAND

By B. J. MOFFITT

Geographical situation.—Thorney Island is situated (see Fig. 1) in a land-locked harbour on the south coast: the South Downs run roughly parallel to the coast with their ridge rising some 600 ft. above sea level about 8 miles north-north-east of the station. The coastal water is very shallow and undergoes considerable temperature variation due both to diurnal effects and changes of weather type.

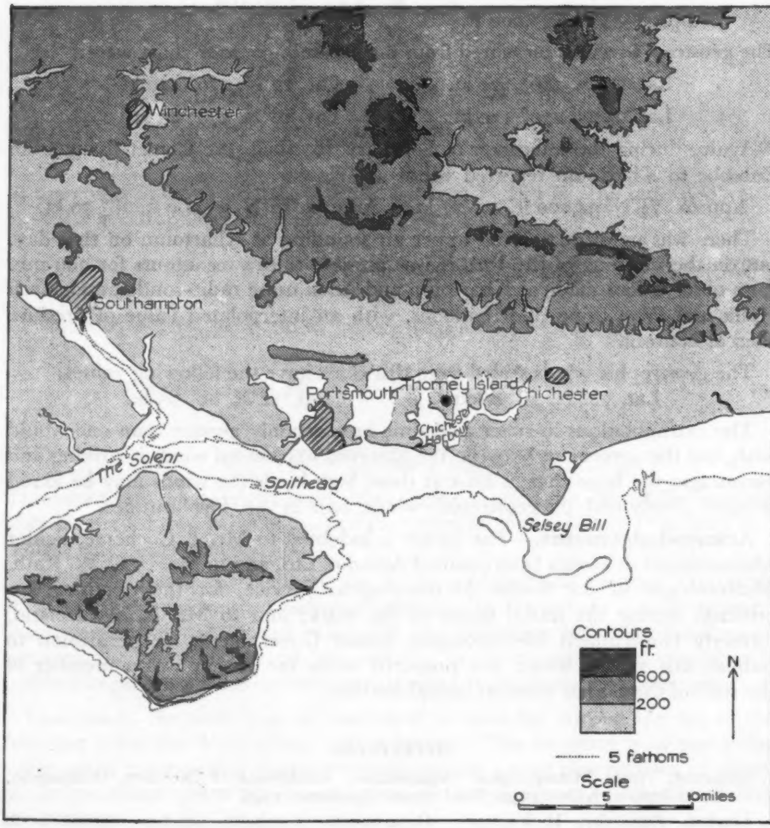


FIG. 1—THORNEY ISLAND AND SURROUNDING DISTRICT

Description of the wind and its importance.—The nocturnal wind at Thorney Island is from NNE. and may occur at any time of the year when clear skies and light winds prevail; with a light on-shore gradient wind there is usually a sudden change of wind direction to about 30° and a sudden temperature fall of some 2°F. The most important effects of the wind are its ability

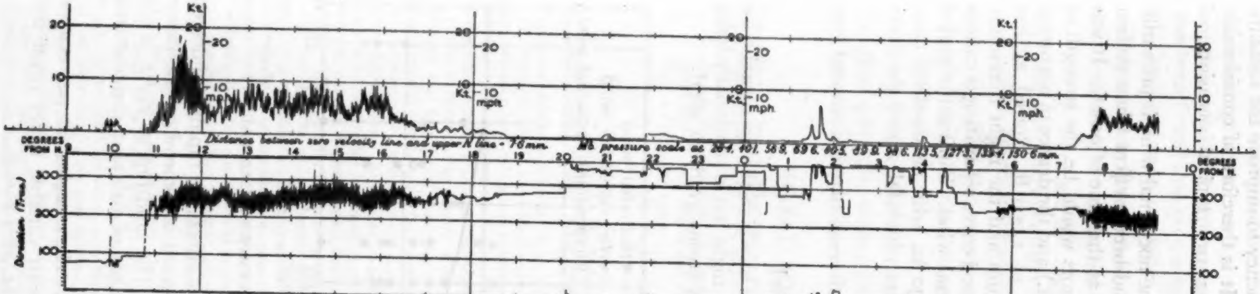


FIG. 2—ANEMOGRAM ILLUSTRATING INTERMITTENT NOCTURNAL WINDS ON NOVEMBER 10, 1953

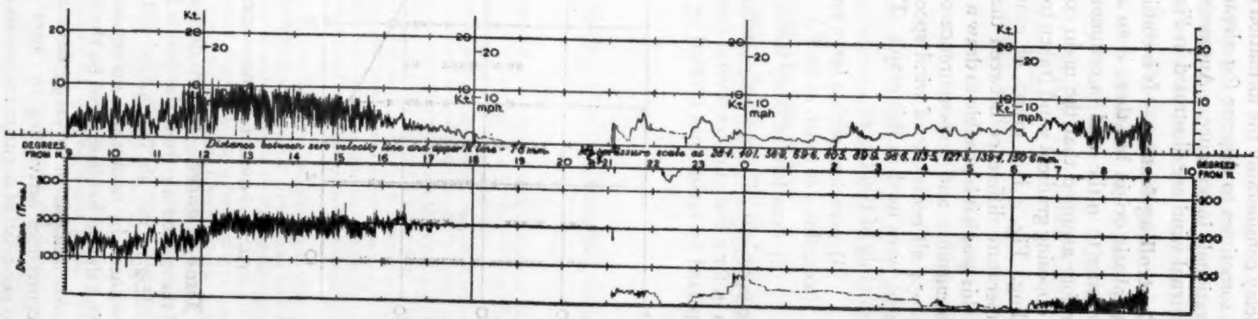


FIG. 3—ANEMOGRAM ILLUSTRATING NOCTURNAL WINDS ON APRIL 9, 1954

to delay considerably the formation of fog, a tendency to improve the visibility and sometimes to disperse fog already formed. It is therefore of considerable operational importance. Anemograms showing two typical occasions of nocturnal wind are illustrated in Figs. 2 and 3.

Controlling factors.—It is considered that the nocturnal wind is primarily of katabatic origin but there is an additional land-breeze effect when the sea is warmer than the land (a common occurrence at the time of onset). It was therefore assumed that the main controlling factors would be the strength of the opposing gradient wind (taken to be at 1,000 ft.) and the degree of nocturnal cooling. Fig. 4 is a graph of estimated wind at 1,000 ft. plotted against temperature difference between the day maximum and the night minimum. On this graph it is possible to draw a reasonably good curve separating occasions of occurrence and non-occurence of the nocturnal wind. During the period 1952–54 all occasions of wind speed less than 30 kt. with an on-shore component were used in this graph. The occurrences which fall above the curve are mainly of two types:

(i) occasions with a large temperature difference between sea and land (sometimes as much as 20°F.)

(ii) occasions of fairly strong gradient wind.

The occasions (ii) are mostly partial occurrences in which the nocturnal wind sets in for a few minutes several times during the night but is continually being dispersed by turbulence created by the relatively strong gradient wind.

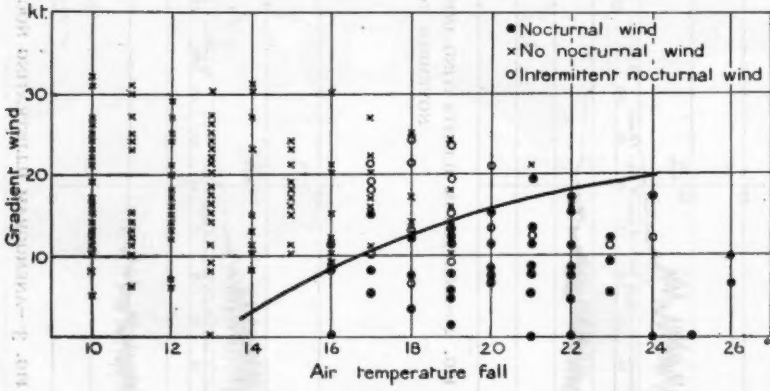


FIG. 4—GRAPH OF GRADIENT WIND AND TEMPERATURE FALL

Time of onset.—In considering the katabatic effect, the rapidity of descent of the cooled air from the South Downs is expected to depend on the rate of cooling of the air in contact with the slope. The land-breeze effect is also enhanced by nocturnal cooling and hence the time of arrival of the nocturnal wind should be dependent on the rate of cooling.

An analysis of 1952–54 data shows that on clear nights 68 per cent. of occurrences arrive 2–4 hr. after sunset but with variable cloud cover over 90 per cent. of occurrences began more than 4 hr. after sunset.

Since the nocturnal wind thus appears to occur much earlier on clear nights than on nights with variable cloud, it is not surprising that nearly all occurrences can be correlated with a particular fall of temperature at Thorney Island. It has been found that 90 per cent. of all occurrences arrive when the temperature at Thorney Island has fallen by 14–16°F. from the day maximum.

Forecasting procedure.—From the above discussion the following rules for forecasting the nocturnal wind at Thorney Island have been deduced:

(i) Forecast the night minimum temperature and hence deduce the expected fall of temperature from the day maximum.

(ii) Forecast the on-shore wind speed at 1,000 ft.

(iii) Plot the temperature fall and the on-shore wind speed at 1,000 ft. on Fig. 4 and read off whether a nocturnal wind is probable, improbable or marginal.

(iv) Consider whether the wind may arrive earlier than 2 hr. or later than 4 hr. after sunset, bearing in mind the coastal sea temperature and the expected cloudiness.

ROYAL METEOROLOGICAL SOCIETY

The Annual General Meeting of the Royal Meteorological Society was held on April 25 with the President, Dr. R. C. Sutcliffe in the Chair. After the formal business the following awards were made:

Buchan Prize: Mr. F. H. Ludlam.
Hugh Robert Mill Medal and Prize: Mr. J. S. Sawyer.
Darton Prizes for 1955:
Home, 1st: Mr. R. J. Murgatroyd.
2nd: Mr. S. E. Ashmore.
Canada, 1st: Mr. Roy Lee.
2nd: Mr. R. Anderson, Mr. B. W. Boville and Mr. D. E. McClellan, jointly.

Dr. Sutcliffe then delivered his Presidential Address.

Presidential Address—Moisture balance of the atmosphere.

Dr. Sutcliffe would have liked to have discussed the general circulation of the atmosphere which was curiously ignored in this country, but this was too wide a subject and he therefore confined himself to a talk about the water circulation in the atmosphere. There were three main parts to the circulation: evaporation, transport in the form of vapour or clouds, and precipitation.

It was convenient to assume that all condensation below the dew point would produce rain although this was clearly not the case. Precipitation, in the macrodynamic as opposed to the microphysical sense, could be classified into three types: orographic, convective (associated with vertical instability and of 1–10 Km. horizontal dimensions) and cyclonic (of 1,000 Km. horizontal dimensions). Little data was available about vertical transport of water on any scale yet this was fundamental in convective precipitation which was the main type in tropical regions. North of, say, 30°N. horizontal transport was predominant and exchange of moisture took place by eddy fluxes on the cyclonic scale.

For the tropics on the other hand, Palmén had shown that a reasonable proportion of equatorial rainfall can be accounted for from the trade-wind influxes, i.e. from mean and not eddy winds. The implication was that the circulation of water vapour in temperate regions occurs because there are eddy systems whereas in the tropics the circulation is due to convection. The tropical cyclone is a hybrid between a temperate-zone depression and a convective cell on a little smaller scale than a temperate-zone depression; it is a type of latent instability due to the release of latent heat. Possibly a small increase in temperature in equatorial regions might, as suggested by Bergeron and Palmén, produce a sequence of tropical cyclones in both hemispheres with a W. wind at the equator. Dr. Sutcliffe then showed a diagram having, on a cosine (equal areas) scale of latitude, isopleths of the distribution of water vapour up to 300 mb., the curves rising steadily at a slope of about 45° from pole to equator. He next showed diagrams of the amount of precipitable water over the Earth in January, maximum 5 cm. over the Amazon and 0·5 cm. over the Arctic and Siberia, and July, maximum 6 cm. over north-east India. These diagrams showed a maximum water content where there was most rain. A table of average amounts of precipitable water showed in January 0·9 cm. over the northern hemisphere, 2·5 cm. over the southern hemisphere and 2·2 cm. over the Earth and for July values of 3·4 cm., 2·0 cm. and 2·7 cm. respectively. As the mean amount of precipitation is 90 cm./yr.

the atmosphere holds only 10 days' supply of precipitation and its stock of water vapour must be renewed at that rate. Hence the main reservoir of water was on the Earth and, over a long time, the atmosphere was not of great account.

Turning to the energy requirements of evaporation Dr. Sutcliffe described the work of Albrecht and Budyko on evaporative energy transfer and pointed out that the energy used in evaporation is only a small part, 18 per cent., of the total energy of insolation.

Finally he showed a slide of Albrecht's figure of areas over which heat was transferred from the Earth to the atmosphere and *vice versa*. Heat was put into the atmosphere from the Earth in the equatorial regions and over the Gulf Stream and taken out of the atmosphere by the Earth in the subtropics. The pattern of input of energy from Earth to atmosphere corresponded with that of rainfall. Dr. Sutcliffe pointed out that the diagram showed it was not realistic to suppose, as was sometimes done, that the air received energy from the Earth all over the tropics and lost energy to the Earth in the temperate and polar regions.

LETTERS TO THE EDITOR

Whirlwind at Mitcham, May 18, 1956

Here are details of the whirlwind which struck my son-in-law's shed, Deer Park Gardens, Mitcham, Surrey on Friday, May 18, 1956. The incident occurred about 9 o'clock in the evening. The whirlwind sounded like an express train and the air was very cold. My son-in-law saw the whirlwind approaching and

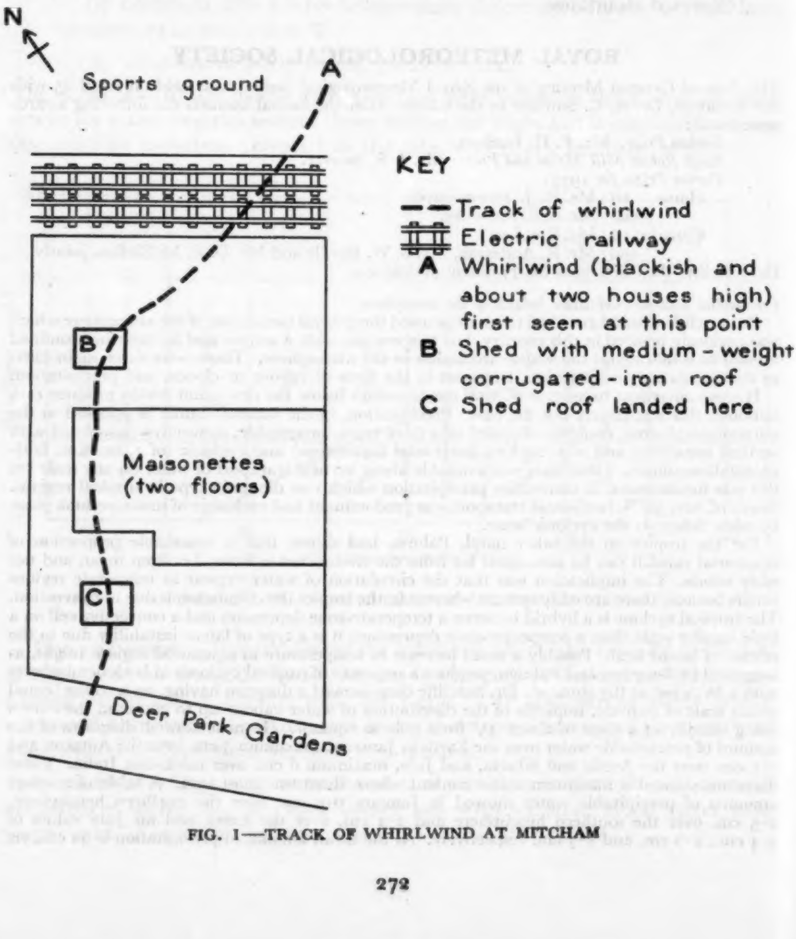
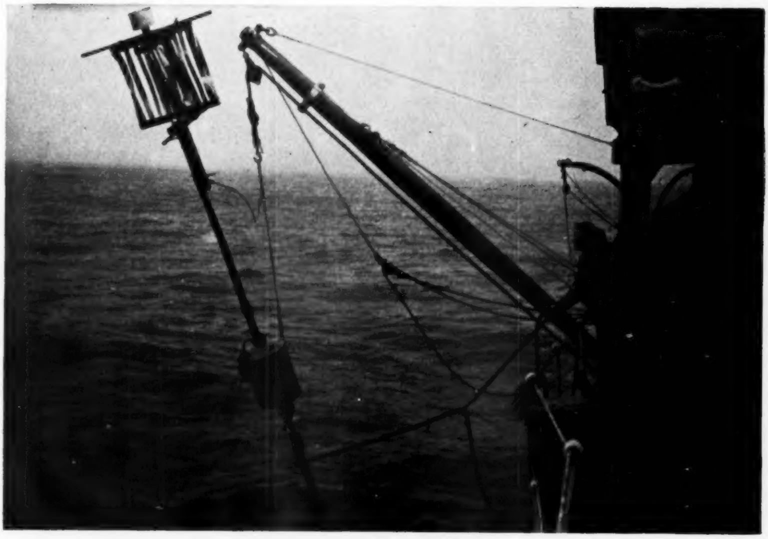
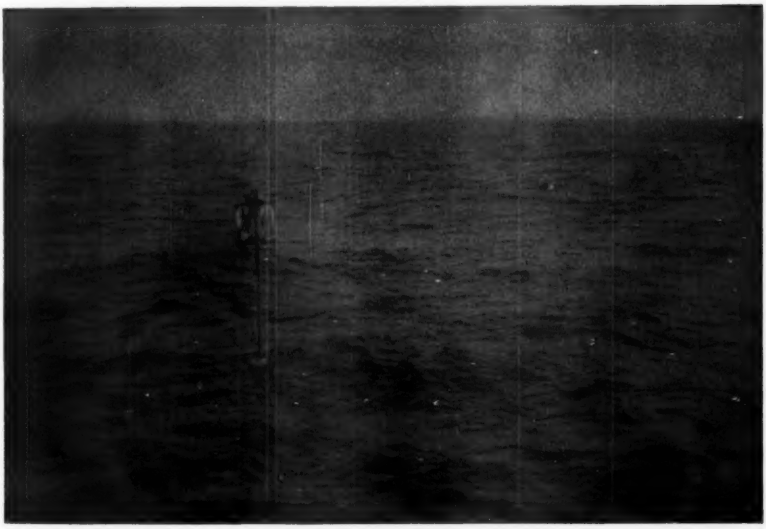


FIG. 1—TRACK OF WHIRLWIND AT MITCHAM

[*To face p. 272*



DAN BUOY BEING HOISTED INBOARD



DAN BUOY AFLOAT

Electrical-resistance thermometers are attached to the Dan buoy in order to investigate air and sea temperature gradients near sea level.

Reproduced by courtesy of E. M. Nicholson

DUST DEVIL, CAVENHAM HEATH, NOON, APRIL 23, 1956
(see p. 273)

DUST DEVIL, CAVENHAM HEATH, NOON, APRIL 23, 1956
(see p. 273)

Reproduced by courtesy of E. M. Nicholson

DUST DEVIL, CAVENHAM HEATH, NOON, APRIL 23, 1956
Taken near Ash Plantation on Cavenham Heath Nature Reserve looking south-east over Black Ditches.

(see p. 273)

To face page 273]

Photograph by H. G. Biggs

SILVER BIRCH TREE STRUCK BY LIGHTNING

The tree, at Whiteley Village, Walton-on-Thames, was struck at 0630 B.S.T. on July 9, 1956 during a severe thunderstorm when 2·47 in. of rain fell. Bark from the tree was scattered round the base, the furthest piece being 12 ft. away. The incident was reported by G. B. Chetwynd-Stapylton, warden of the Whiteley Homes Trust.

threw himself to the ground. When he arose he found the shed roof had disappeared—this he subsequently found in the front garden. The diagram (Fig. 1) may help you to visualize what happened.

C. F. MACLAREN

16 *St. Aidan's Road, East Dulwich, S.E.* 22, *May* 23, 1956

[On May 18, 1956 the air over south-east England was cold and unstable in the lower layers. Winds were light and northerly. A few slight showers of rain were reported and at Kew the duration of sunshine was 6·7 hr.—Ed. *M.M.*]

Low latitude aurorae and the International Geophysical Year

The recent report of the Meteorological Office Discussion on the International Geophysical Year has prompted me to make the following suggestion to readers who live or who will be travelling in the regions named. One of the characteristics of sun-spot maxima is the extension southward of great auroral displays, the absolute records being Singapore (1°N.) and Batavia (6°S.) on September 25, 1909*. May I suggest that those whom duty or business or pleasure take to the East Indies, the Caribbean, and the Canal Zone during the International Geophysical Year keep a special watch for auroral activity.

CICELY M. BOTLEY

2 *Park Road, Tunbridge Wells, May* 29, 1956

NOTES AND NEWS

Dust devil on Cavenham Heath, April 23, 1956

We are indebted to the Director General of the Nature Conservancy for the two photographs in the centre of this magazine which were taken on Cavenham Heath Nature Reserve, Suffolk, at noon on April 23, 1956. The dust devil was moving from a north-easterly direction (left to right on the photographs) and the interval between the two exposures was about one min. At 1200 G.M.T. there was a weak cyclonic circulation of cold air over East Anglia and the screen temperature at Mildenhall (3 miles to the north-west of Cavenham Heath) was 52°F. The average lapse rate of temperature at Hemsby, Norfolk, up to 850 mb. was slightly less than 1°C./100 m.

Beiträge zur Physik der Atmosphäre

In the April number of the Magazine we announced the forthcoming publication of the new periodical, *Beiträge zur Physik der Atmosphäre* and stated the names of the publisher and editors. We are now pleased to report the publication of the first number which contains four major articles.

The first article is a memorial by H. Koschmieder to the scientific and administrative work of Richard Assmann. It includes a tribute to Dr. F. Schmidt-Ott a civil servant who was very instrumental in securing financial support, against his own superiors' wishes, for Assmann's work. Dr. Schmidt-Ott, founder of the *Notgemeinschaft der deutschen Wissenschaft*, died in April at the age of 95.

The research articles are by J. Zierep on the theory of lee waves in the stratosphere and troposphere taking account of suitable boundary conditions at the ground and tropopause, by A. J. Abdullah on dust storms in Iraq showing their occurrence along pre-cold-front pressure-jump lines and describing the

* STØRMER, C.; The polar aurora, Oxford, 1955, p. 17.

storm of March 23, 1954 in detail, and by H. v. Tippelskirch on the reason for the opposite sense of flow in Bénard cells in liquids and gases. The number is very well printed on 54 crown-octavo art-paper pages. The price of a volume of four numbers is 55.DM.

The dry weather in England and Wales during the first half of 1956

The first half of 1956 was notable for a long dry spell of weather which in many places lasted for nearly four months. Absolute droughts were reported as detailed below from a number of districts, principally in southern England. An absolute drought is a period of at least 15 consecutive days to none of which is credited 0·01 in. or more of rain. At first the general pattern of rainfall in England and Wales seemed to be following that of the great drought of 1921 when a wet January was followed by a long series of exceptionally dry months, but fortunately, in 1956, the series did not continue into June, as nearly twice the normal amount of rain fell over the country as a whole during the two weeks ending on the 9th and 16th of that month.

During February rainfall over England and Wales was only about 44 per cent. of the average, and apart from 1952 which had about the same amount of rain during that month, there has been no drier February since 1934. Less than one tenth of an inch was recorded at each of many places along the south-east coast of England and absolute droughts occurred from about the 13th to the 29th in the London area and in south coast counties from Kent to Devon.

March had about the same percentage of the average rainfall as February, and again the southern part of the country was the driest. Much of Kent, Sussex, Hampshire, Wiltshire and Gloucestershire experienced less than a quarter of the usual amounts. Absolute droughts occurred from the 4th to the 19th mainly south of the Thames and south-east of a line from about London Airport to the Isle of Wight.

April had 76 per cent. of the average for the month. Absolute droughts were reported from about March 24 to April 9 along the south coast of England at places extending from Bournemouth to Torquay and also along the south Welsh coast. Droughts also occurred later in the month in Northamptonshire, Huntingdonshire and Norfolk from about April 14–30.

It was the driest May in England and Wales since 1896 with only 41 per cent. of the month's average rainfall. Absolute droughts occurred at many places in East Anglia from about April 14 to May 8, and also locally in the Home Counties from May 10–24.

A map of the amounts of rain measured at a large number of stations during the period February–May 1956 and expressed as a percentage of the 1881–1915 average shows that everywhere in England and Wales for the same four months the rainfall during this period was less than 75 per cent. of the average except locally in Yorkshire. It was locally less than 50 per cent. in the English Lake District and generally less than 50 per cent. over most of England and Wales south of a line drawn approximately from Aberystwyth to Cambridge and thence to Southend, and was locally less than 33 per cent. in the Thames Valley and along much of the south coast. Graphs of accumulated departures from the average amount of rainfall drawn for six representative stations well dispersed over the country show that during the 17 weeks from January 29 to May 26 rainfall was below the average almost every week and that the

deficiency amounted to about 4 in. in the south and 3 in. elsewhere in the country. Outstandingly dry places were South Farnborough, which usually has over 7 in. during the periods February–May, with a deficit of 5·4 in., and Princetown (Devon) which recorded 15 in. less than its usual fall of 24 in.

The effects of the dry weather during the first half of 1956 were all the more serious as 1955 was a dry year, especially during the second half when the rainfall over England and Wales was 7 in. below normal; the accumulated deficiency over the 12 months amounted to 4 in. The four months February–May 1956 with only 4·8 in. was the driest period from February–May on record since, at least, 1869; the driest four-month period was March–June 1893 with 4·2 in. The 11 months July 1955–May 1956 with only 23·8 in. (10 in. below the average for this period) was also the driest of any similar period of 11 months since records began in 1869.

Over Scotland as a whole the dry weather of February–May 1956 was not so pronounced as over England and Wales. A large area in the north and west had over 75 per cent. of the average and locally there was a close approach to the average. In many parts of the east and south however, there was only 50–60 per cent. of the averages and in the neighbourhood of Edinburgh in particular the deficiency combined with deficiencies of earlier months to make December 1954—May 1956 the driest 18 months on record.

R. E. BOOTH

Strong winds at high levels in the equatorial zone of the Far East

Strong winds (exceeding 75 kt.) have been noted from time to time in the band between 40,000 and 55,000 ft. in the winds derived from radar-wind-measurement stations in the Far East equatorial zone (regarded as the zone between 10°S. and 10°N. for the purposes of this note). Reference has been made to the winds at these levels by Hay[1].

Since the arrival of Canberra aircraft in Malaya early in 1955, more aircraft reports of winds at heights above 40,000 ft. have become available in addition to the sparse radar observations. From these, we conclude first, that the sparsity of radar wind-measurement stations over a vast area, coupled with the system used in coding the results for transmission which allows for reporting standard heights only, has probably been the cause of many occasions of strong winds being unnoticed; secondly, that somewhere in the layer between 40,000 and 55,000 ft. there often exists a narrow "core" of strong easterlies, often exceeding 75 kt. and occasionally exceeding 100 kt., with comparatively light winds above and below the "core". In fact it is not uncommon at the time of year to which this note relates (late May to July) to find a change to westerlies a few thousand feet above the core of strong easterlies, as shown by Hay[1]. The height of the "core" appears to vary from day to day, as does the orientation of its axis. There are insufficient data to be able to correlate the surface or lower-level streamline charts with the day-to-day movement of the "core".

An example of the existence of such winds which, from available data, would have been impossible to forecast, occurred on a flight by a Canberra from Negombo to Butterworth (overflying Car Nicobar Island) on June 19, 1955. Flying at an indicated height of 46,500 ft. the mean wind found between Negombo and Car Nicobar was 82° 102 kt., with a maximum computed to have been

120 kt. The mean wind between Car Nicobar and the let-down point near Butterworth was 80° 86 kt.

Another example occurred in a flight by another Canberra over the same route on July 26, 1955. Flying at 47,000 ft. the mean wind from Negombo to 250 miles from Butterworth was 75° 80–90 kt. A marked decrease occurred about 250 miles from Butterworth.

A third example occurred in a flight by a Canberra from Changi to Labuan and return on May 27, 1955, spending one hour between 0500 and 0600 G.M.T. over Labuan. Flying at heights between 40,000 and 45,000 ft. (indicated) the mean wind on the outward flight was 85° 50 kt. Flying at 42,000 ft. the mean wind on the return flight was 85° 60 kt. On the outward flight flying at 40,000 ft. two winds of 82° 99 kt. and 72° 105 kt. were computed at 0347 and 0353 G.M.T. respectively. On climbing to 43,000 ft. a wind of 85° 40 kt. was computed at 0413 G.M.T. On further climbing to 45,000 ft. winds of 65° 49 kt. and 85° 70 kt. were computed at 0420 and 0440 G.M.T. respectively.

TABLE I—UPPER WINDS AT STATIONS NEAR THE AIR ROUTES

	May 26, 1955 Singapore 0300 G.M.T.		May 26, 1955 Singapore 1500 G.M.T.		May 26, 1955 Songkla 0300 G.M.T.		May 27, 1955 Singapore 0300 G.M.T.		May 27, 1955 Singapore 1500 G.M.T.		May 27, 1955 Songkla 0300 G.M.T.	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
55,000	110	25	100	48	90	35	...	...	100	18	...	...
50,000	90	30	80	52	100	46	...	...	60	56	90	16
45,000	110	35	90	35	80	52	...	...	50	53	70	33
44,000	...	...	...	...	...	...	80	47	...	...	...	...
43,000	100	44	...	...	...	...	...	...	...	...	...	...
40,000	100	14	110	21	70	35	90	39	70	49	90	25

	June 18, 1955 Bangkok 0300 G.M.T.		June 18, 1955 Singapore 0300 G.M.T.		June 18, 1955 Singapore 1500 G.M.T.		June 19, 1955 Bangkok 0300 G.M.T.		June 19, 1955 Singapore 0300 G.M.T.		June 19, 1955 Singapore 1500 G.M.T.	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
55,000	70	93	90	40	...	...	...	...	20	7	70	36
54,000	...	...	...	...	...	...	...	...	70	26	...	...
53,000	...	...	...	...	...	...	...	...	...	...	60	78
52,000	...	...	...	...	...	...	...	...	70	78	...	...
51,000	...	...	60	74	...	...	...	...	...	...	50	88
50,000	80	67	60	72	...	...	70	106	60	63	50	81
47,000	...	...	...	...	70	69	70	87	...	...	...	...
45,000	90	54	70	47	80	53	70	82	...	...	50	46
40,000	70	45	70	44	80	40	80	49	90	39	70	29

	July 25, 1955 Bangkok 0300 G.M.T.		July 25, 1955 Singapore 0300 G.M.T.		July 25, 1955 Singapore 1500 G.M.T.		July 25, 1955 Songkla 0300 G.M.T.		July 26, 1955 Bangkok 0300 G.M.T.		July 26, 1955 Singapore 0300 G.M.T.		July 26, 1955 Singapore 1500 G.M.T.		July 26, 1955 Madras 0300 G.M.T.		July 26, 1955 Songkla 0300 G.M.T.	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
55,000	90	102	...	...	60	43	10	46	...	...	70	37	90	16	...	...	80	30
51,000	...	...	...	...	70	58	...	...	...	...	...	...	...	...	...	...	...	...
50,000	...	...	90	40	70	52	80	102	90	69	70	44	90	52	...	...	50	91
49,000	...	...	...	...	...	...	...	...	...	...	...	...	100	54	...	...	...	...
48,000	...	...	80	54	...	...	...	...	...	...	...	...	...	...	...	...	...	...
47,000	80	106	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
45,000	...	...	100	40	60	41	60	45	80	63	80	50	90	49	...	...	60	73
40,000	70	69	80	30	70	36	90	33	60	40	80	38	80	39	90	94	90	89

The Canberra aircraft which made the flights from Negombo to Butterworth were able to "pin-point" Car Nicobar. The airspeed indicator and "machmeter" provided a cross check for airspeed. R/T communication was possible with Car Nicobar and Butterworth. The degree of accuracy of the winds computed is calculated to be $\pm$ 10 per cent. for speed and $\pm$ 10° in direction. The heights are underestimated a little because in this area aircraft altimeters (based on an international standard atmosphere) underread to the extent of 1,000–2,000 ft. between 40,000 and 50,000 ft. The aircraft which made the Labuan flight had the same navigational aids but, in addition, radio "beams" gave first-class fixes throughout the route. A somewhat higher degree of accuracy of computed winds was therefore to be expected.

As experience in the forecasting of high-level winds in the area is limited and a number of different techniques are being compared, the existence and day-to-day movement of the all important "core" of strong winds is a problem of some concern.

Actual winds found by the radar wind-measurement stations situated nearest to the routes are given in Table I.

P. F. EMERY

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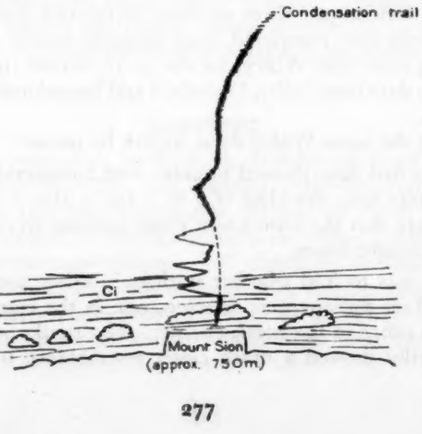
An orographically generated jet stream?

The sketch reproduced below shows an unusual condensation trail seen on September 30, 1954 at 1115 near Mount Sion, Haute Savoie, France. A photograph taken of the phenomenon was unsuccessful as the writers had no suitable filter.

The most unusual feature of this condensation trail is the spectacular lateral distortion in the lower portion. This distortion had already taken place when the condensation trail was first seen, and remained virtually constant throughout the period of some 15-20 min. during which it was under observation. It was thought to be associated with high-level wind shear, perhaps caused by a jet stream, but examination of the relevant upper air data by the writers failed to establish any such connexion.



As similar phenomena have often been observed in Switzerland, mostly just under or just above the tropopause, it is thought that it was associated with local effects produced by mountainous terrain. On one occasion a Venom pilot over that country reported severe turbulence in the area of a similar condensation-trail distortion, and concluded from his marked drift that it was produced by a local jet stream. On this particular occasion, June 11, 1954 and some 20 hr. before the arrival of an active warm front, the turbulence was found to be in a thin layer of about 200–300-m. thickness and the width varied from about 20 to 50 Km. The length could only be guessed, but was estimated at 200–300 Km. These phenomena are thought to be associated with local jet streams at heights between 9,000 and 11,000 m. In the course of 12 months' observation by one of the writers the maximum height at which condensation trails formed was 11,500 m. A watch is being kept for further similarly distorted condensation trails.

No attempt has been made to attach heights to the diagram because of the distance at which the condensation trail was observed. It is pointed out that no connexion with the 750-m. mass of Mount Sion is intended, this mountain only appearing to be beneath the condensation trail from the point of observation. It is suspected that the disturbance had its origin in the much higher ground to the north-west where, in the western Swiss canton of Vaud, the Jura Mountains reach 1,500–2,000 m. That high-level turbulence is not an inevitable result of mountains on this scale is shown by an occasion when a condensation trail 40 Km. in diameter at an altitude of 10,000 m. (aircraft measurement) drifted south-eastwards for over an hour without distortion.

The only other examples of marked " kinking" of a condensation trail which can be traced are those noted in the *Meteorological Magazine* for April 1953 and July 1955.

P. ROGERS

J. KELLER-HAMMER

Relation between 0900 G.M.T. cloud amount and sunshine total

The objective was first to establish an empirical relation between average cloud amount (y), in tenths, observed at 0900 G.M.T. and average sunshine (x), expressed as a percentage of possible, at one station, and then to determine whether the results may be satisfactorily applied to another station.

The work was divided into three sections: correlation coefficients and linear regression equations were computed, from monthly means of x and y

(i) using data from Wisley, for the 20-yr. period 1931–50,

(ii) using data from Scilly, Wakefield and Stonyhurst for 10-yr. periods, as available,

(iii) using the same Wisley data, month by month.

Results.—The first stage showed promise, with a reasonably high correlation and equations quite near the ideal of $x = -10y + 100, y = -(1/10)x + 10$, which would imply that the 0900 G.M.T. cloud amount completely represented the mean over daylight hours.

The next step was to find whether stations in other situations would give similar results. Two stations were selected, one in the extreme south-west of England and the other in the north country. The results were against expectation in that Scilly showed a much closer resemblance to Wisley than did

Wakefield. This could be due to smoke at Wakefield, and to check this, data from a third station, Stonyhurst, were treated in the same manner and found to be somewhat closer to the southern stations.

	Period	Correlation coefficient	Mean cloud	δy	Mean sun	δx	Regression equations	
			tenths		*per cent.*			
Wisley	1931–50	−0·79	7·4	0·96	30·3	11·63	$x=-9{\cdot}71y+102{\cdot}16$	$y=-0{\cdot}066x+9{\cdot}40$
Scilly	1945–54	−0·80	7·4	0·90	37·2	11·55	$x=-10{\cdot}22y+112{\cdot}68$	$y=-0{\cdot}062x+9{\cdot}71$
Wakefield	1931–40	−0·57	7·4	0·72	23·4	10·81	$x=-8{\cdot}52y+86{\cdot}66$	$y=-0{\cdot}038x+8{\cdot}29$
Stonyhurst	1931–40	−0·75	7·4	0·93	27·9	10·63	$x=-8{\cdot}50y+90{\cdot}77$	$y=-0{\cdot}066x+9{\cdot}23$

So far, only the year as a whole had been considered. To determine whether there was an acceptably small variation between the months the 20-yr. Wisley data were used. As may be seen, there was found to be a large variation in the relation with a general tendency to be closer in summer than in winter, possibly due to the differing time of sunrise.

	Correlation coefficient	Mean cloud	σy	Mean sun	σx	Regression equations	
		tenths		*per cent.*			
Jan.	−0·68	8·1	0·50	17·0	4·12	$x=-5{\cdot}59y+62{\cdot}28$	$y=-0{\cdot}084x+9{\cdot}53$
Feb.	−0·92	7·7	0·89	22·5	8·76	$x=-9{\cdot}04y+92{\cdot}11$	$y=-0{\cdot}094x+9{\cdot}81$
Mar.	−0·72	7·3	0·73	31·5	7·99	$x=-7{\cdot}89y+88{\cdot}76$	$y=-0{\cdot}066x+9{\cdot}36$
Apr.	−0·90	7·2	0·99	36·4	9·59	$x=-8{\cdot}75y+99{\cdot}36$	$y=-0{\cdot}093x+10{\cdot}59$
May	−0·74	7·0	0·77	38·4	7·18	$x=-6{\cdot}89y+86{\cdot}63$	$y=-0{\cdot}080x+10{\cdot}07$
June	−0·84	6·8	0·90	42·5	5·77	$x=-5{\cdot}41y+79{\cdot}29$	$y=-0{\cdot}139x+12{\cdot}71$
July	−0·88	7·1	1·15	38·6	10·09	$x=-7{\cdot}74y+93{\cdot}55$	$y=-0{\cdot}101x+10{\cdot}98$
Aug.	−0·89	6·9	1·04	39·8	7·26	$x=-6{\cdot}19y+82{\cdot}50$	$y=-0{\cdot}128x+11{\cdot}99$
Sept.	−0·90	7·0	0·90	35·0	7·74	$x=-7{\cdot}77y+89{\cdot}39$	$y=-0{\cdot}105x+10{\cdot}69$
Oct.	−0·37	7·5	0·74	27·7	4·25	$x=-2{\cdot}11y+43{\cdot}50$	$y=-0{\cdot}064x+9{\cdot}27$
Nov.	−0·69	7·9	0·65	18·5	4·89	$x=-5{\cdot}22y+59{\cdot}74$	$y=-0{\cdot}091x+9{\cdot}58$
Dec.	−0·69	8·0	0·68	16·3	4·73	$x=-4{\cdot}77y+50{\cdot}46$	$y=-0{\cdot}100x+9{\cdot}63$

The scale of this monthly variation shows that no simple expression can be used. While it is possible to obtain a close correlation between these two variables for any one station, the results cannot successfully be applied to other areas, smoke pollution and latitude probably being large factors in the variation.

D. T. TRIBBLE

REVIEWS

Land, air and ocean. 2nd edn. By R. P. Beckinsale. 8¾ in. × 5⅝ in., pp. 370, *Illus.*, Gerald Duckworth & Co., Ltd, London, 1956. Price: 25*s*.

The preface states this book's objective, namely to cater for "the general public who are interested . . . , though it has been written primarily for students at universities and training colleges. . . ." Evidently the earlier edition published in 1943 has found a certain popularity in serving these purposes. The preface to the new edition adds that ". . . recent advances in physical geography, particularly in the study of climate, land-forms and oceans have been incorporated."

It comes as something of a shock to find on p. 82 that climate is defined as nothing more nor less than "the average state of the atmosphere at a given point".

The book has in fact, a number of obvious merits. It covers a wide field of information, providing a wealth of well chosen illustrative material, quoting figures and giving on the whole well chosen diagrams. The text is in the main well written in reasonably simple, direct English. About 100 pages are devoted to climate. The best sections and paragraphs are those which are strictly geographical and wherein some bearing upon adaptation of human activities to environment is explained. Here the writing is imaginative in the best sense and shows real understanding, as for instance on p. 100 "many Swiss villages are perched at considerable altitudes above the valley floor, the two or three hours increase in sunshine thereby gained being deemed a recompense for difficulties in transport". There are also good bibliographies for further reading on the subject matter of each chapter. Many of the diagrams, however, including those reproduced on the paper cover, are without adequate explanation of the symbols used.

The figures quoted in the text are made hard to assimilate by being all in English units. Nowhere will the reader be led to suppose that there are other units for measuring the pressure of the atmosphere or of atmospheric water vapour than inches of mercury. Water-vapour content is given in grains per cubic foot. Surely it is indefensible today to familiarize students with all temperatures, whether of the air or produced by radio-active processes in the earth's interior and in the sun, solely in terms of the awkward Fahrenheit scale. The Celsius scale has crept into the chapter on vulcanism. Really, in spite of the layman's conservative addiction to the *ad interim* temperature scale of Fahrenheit of Danzig, it is precisely the layman who would gain most from the simplicity of the Celsius scale on which the most obviously critical temperature is 0°, 10° represents mild winter days in the temperate zone, 20° marks genial spring warmth (and good water for outdoor bathing) and 30° stands for tropical heat. The reviewer wonders how many readers will be sure what is meant on p. 86 by "below zero".

In the realm of physical description and explanation of atmospheric phenomena some of the statements offered are more seriously clumsy or misleading. There is an odd insistance on p. 103 and elsewhere that katabatic winds are the gentle "creep" of cold air draining into the hollows in the English landscape on radiation nights and are not to be confused with the fierce cold gales off ice caps and other mountain regions. On p. 52 tropical cyclones and tornadoes are equated as "small revolving storms . . . an extremely localized form of convection".

On p. 57 it is asserted that "spring is the snowy season in the British Isles"—an overstatement which makes nonsense. Even in our most maritime western and northern districts the maximum frequency of snow appears to be in late February and early March. Presumably the carry-over of this maximum into March is counted as a technical trespass on the part of the atmosphere! On p. 72 the phrase "from late September onwards, when the overhead position of the sun begins to move southwards . . ." really will not do. On p. 73 the writer shows discernment in linking the mild winter weather of our Atlantic coast districts with dull skies and drizzle; but the comparison on the same page with

the "usually intensely blue cloudless sky" in winter in the Mediterranean is less than fair. This is a time-worn misconception which beguiles English travellers into spending money on expensive fares to places in the Mediterranean where the winter rainfall is often double that of London, the number of rainy days about the same and the windiness much greater than in our inland districts. The blue skies are really a predominant feature only in those districts (the French Riviera especially and the south-east coast of Spain) which enjoy orographic shelter from the prevailing winds and in the African interior.

The greatest disappointment is perhaps to find anticyclones and some depressions still explained largely in terms of Abercrombie, though with some slight indication of frontal patterns and behaviour included. It is surely time someone wrote an up-to-date and acceptable account of the general circulation of the atmosphere and development of surface-pressure systems in terms that every serious student can understand. The fundamental concepts of development in association with the accelerations and retardations in the flow of the main streams of upper wind are not difficult. This book, however, does not attempt it.

H. H. LAMB

The theory of hydrodynamic stability. By C. C. Lin. *Cambridge Monogr. Mech. appl. Math.* 9 in. × 5½ in., pp. xii + 156. Illus., Cambridge University Press, Cambridge, 1955. Price: *22s. 6d.*

Meteorologists have to deal with instability at all scales of motion in the atmosphere, starting with the smallest-scale turbulence and ending with the long waves in the westerlies or, perhaps, with the general circulation itself. In between there is a multitude of phenomena: clear-air turbulence and condensation trails, the motion of air above a heated surface and convection cloud, the motion of air past an obstacle and the creation of lee waves spring to mind at once. Usually the interest, meteorologically speaking, lies in the motion after instability has set in; e.g. it is turbulence rather than laminar flow which is important. However, the meteorologist has often to estimate the stability of an air stream from a few gross characteristics (and in fact has often to make one further step and first forecast the gross characteristics and hence the future stability). Some of the problems are successfully attacked and one thinks immediately of the forecasting of thundery rain and showers. Other problems are not nearly so easy, such as the estimation of the characteristics of waves in the lee of a mountain. Any book which deals with hydrodynamic stability must be of practical interest to meteorologists in view of the diversity of the applica-ions and the difficulty of most of the problems.

Prof. Lin's book deals with the stability of flow after a small perturbation has been applied so that much of it deals with linearized theory and not with the large-scale departures from the mean field of motion; the meteorological interest lies less in the quantitative prediction, such as the dissipative changes caused by turbulent flow, than in the prediction that a phenomenon will occur, such as predicting that instability will set in in a certain air stream, given that some criterion is satisfied. The fourth chapter is the most important in the book; here the author discusses, with little mathematics, the general theory of hydrodynamic stability using physical arguments and bringing well to the front the role played by viscosity. The ideas expounded have of course already

been applied to meteorological problems such as the stability of the westerlies and the formation of waves. Chapter 7 gives examples of stability problems and includes two very important meteorological problems—the stability of zonal winds and the convective motion of a fluid heated from below. In each case the treatment is very short indeed, although references are given to the literature, and the results in the former case might not be accepted by everyone. This chapter could well have been expanded.

From a meteorologist's point of view the other chapters are not so interesting as these two, except perhaps to some specialists dealing with the flows which are treated, because in the atmosphere we rarely find stable flows about to become unstable, but usually find the turbulent state. The first three chapters develop the stability problem from the Navier-Stokes equations for Couette and Poiseuille flow and indicate the methods used in solving the differential equations. The fifth chapter gives the stability theory for boundary-layer flow over a flat plate, with many results including the flow of a perfect gas. The sixth deals with the stability under various boundary conditions, including heating and cooling, injection of fluid and the effect of curvature at the boundary, while the last chapter deals with the mathematical theory of the stability of parallel flows, showing the difficulties that arise. A bibliography completes the book: several meteorological papers are included although they deal with rather different aspects of stability from those treated in the text. There is an author index but no subject index, perhaps because the chapters are set out in well defined paragraphs; nevertheless, a subject index does help the reader who wants to find quickly if and where a problem has been treated.

The printing and the lay-out of the mathematics are of the excellence that one associates with the publishers and the proof-reading seems to have been particularly good. The price of this series of monographs remains reasonable and meteorologists are lucky to find two of the first five volumes devoted to subjects which are important to them.

E. KNIGHTING

The polar aurora. By C. Størmer. *Int. Monogr. Radio.* $9\frac{1}{2}$ in. × $6\frac{1}{4}$ in., pp. xx + 404 + 34 plates, *Illus.*, Oxford: Clarendon Press. London: Cumberlege, 1955. Price: 55*s*.

This book is the fourth in the series "International monographs on radio", which are designed to produce an up-to-date account of the position in a scientific field connected with radio, the field being largely determined by the interests of the author. This is reflected in the volume under review which has been written by an outstanding research worker in the field of auroral studies, one of the first to start the systematic measurement and observation of the polar aurora.

The book is divided into two parts; the first part deals with the results of the observations and measurements of the aurora and thus poses the problem, and the second reviews the attempts which have been made to provide an explanation. Part one begins with a description of the appearance of the aurora and the classification of the main forms which it takes. The difficulties of classifying any particular aurora are not glossed over but the excellent collection of photographs in the book are a great help. This is followed by an account of the geographical distribution of the aurora over the world and of its variations especially during magnetic storms.

The author then describes the method originated and used by himself and his collaborators for measuring the height and position of individual auroral forms by means of photographic triangulation. The large amount of data accumulated by them is described and many interesting features of this work are discussed. Included with this are general hints on photographing aurorae. This is followed by a shorter description of the spectrum analysis of the light from the aurora, and the identification of the main lines is given. Some of the ways by which the emission of these spectrum lines can be caused by particles of high energy falling into the upper atmosphere are discussed. The mechanism of the emission of particles from the sun and the relation of aurora with solar flares and sun-spots is dealt with next, and while there are many aurorae and magnetic storms which seem to be closely linked with individual occurrences on the sun it is pointed out that there are also aurorae which occur when no solar flare is observed and indeed even when there are no sun-spots on the solar disc.

The second part of the book deals with attempts which have been made to explain the way in which aurorae are produced. C. Størmer himself was a pioneer in this field, and he was the first to attempt to calculate the trajectories of charged particles which approach the earth and then come in to the the influence of its magnetic field. The book deals with this problem in some detail and explains fully the various simplifying assumptions that have been made at the various stages and the results obtained. The difficulties in the way of extending the results by eliminating the restrictive assumptions one by one are discussed. These results are then applied to the aurora in an attempt to explain the various forms that occur and to explain the geographical distribution that is observed. It is found that many of the main features are capable of an explanation on this theory but that a number cannot be explained without further development.

The author then goes on to discuss further theoretical work by other workers which deals mainly with the explanation of magnetic storms, or fluctuations in the earth's magnetic field, but which are closely linked with the occurrence of the aurora and which are also thought to be due to particles of high energy entering the upper atmosphere. He deals first with the Chapman–Ferraro theory and a modification of this by D. F. Martyn, and follows this by an account of the electric-field theory by Alfvén and his co-workers in Sweden. The accounts of the last two are given as quotations by the workers concerned and are not critically discussed. The next to last chapter deals with other applications of research into the motion of electric particles in the field of a magnetic dipole which are discussed in earlier chapters.

This book is strongly recommended for anyone who is interested in the subject and needs to find out the basic facts about aurora. The second part is also excellent in the presentation of the work by the author and his collaborators in the explanation of the aurora by means of charged particle trajectories in the earth's magnetic field. It needs however to be supplemented by further reading if a critical knowledge of other theories of auroral formation is required. Full references are however given to enable this to be done. The production and printing of this volume is of the high standard associated with the Oxford University Press. The numerous auroral photographs are excellent.

R. H. COLLINGBOURNE

The Earth as a Planet. Edited by G. P. Kuiper. *Solar system*, Vol. II, 9½ in. × 7 in. xvii + 752, *Illus.*, Chicago University Press, 1955. Price: 94*s*.

This beautifully produced book is the second of an ambitious series of four on the solar system. The first "The sun" was published in 1953 and was very well received. The second maintains the high standard. It was published late in 1954; most of the individual contributions follow developments well into 1953. The dust jacket tells us ". . . it is designed to be both a reference book for the specialist and a source of general information for the reader having some acquaintance with the physical sciences". Specialization is now so narrow and intense that this objective is practically impossible to achieve, but most of the articles will serve as a reference source to all except those in the forefront of progress in the specific subject treated, and by this very fact will call, in the general reader, for a much deeper knowledge of the physical sciences than that usually indicated by the words "some acquaintance".

There are 15 sections each by an author greatly distinguished in his subject. It would be tedious to enumerate them; the standard of scholarship is well illustrated by the first and last "Dimensions and rotation" by Sir Harold Spencer Jones and "Albedo, colour, and polarization" by Prof. André Danjon. The allocation of space will disappoint most meteorologists. The editor, in his preface, says ". . . half the book is devoted to our atmosphere, although its fractional mass is only one millionth. Even so space requirements dictated severe economy. The recent appearance of the 'Compendium of meteorology' made it unnecessary to include many meteorological topics of great potential interest to the planetary astronomer. . . .". We find in fact that Prof. Byers is allowed 70 pages to discuss "The atmosphere up to 30 kilometers", whilst more than 250 pages are devoted to the remainder of the atmosphere. One millionth of the mass has half the book, one part in 107 has a third. The oceans have only 40 pages, contributed by Prof. Sverdrup, so we may expect oceanographers also to feel that quantitative justice has not been granted to them.

Prof. Byers succeeds in his almost impossible task more completely than anyone could fairly expect. He has of course no space for detail, but he gives a rounded picture of the present state of the subject under the headings "Composition and heat balance of the atmosphere", "Distribution of temperature", "Atmospheric circulation", "The secondary circulations", "Tropical cyclones and tropical weather", "Atmospheric electricity", and "Condensation and precipitation". The growing points of the science are indicated, so are, at least by implication, the points which are not responding too eagerly to cultivation. There is no attempt to distribute praise and allocate blame fairly amongst individual workers; this is hardly necessary in an article of this type where space must be put to better use. As a result practically all the literature citations are to American work; the only point on which I suspect an affront to truth, in addition to the many to individual pride, is the quotation of some results of Barrett, Herndon and Carter as the only information on the water content of the stratosphere.

Prof. Sverdrup's article is similar in style to that of Prof. Byers, and since the greater part of it is concerned with the heat budget of the oceans and the surface currents it will be of equal interest to meteorologists. A more detailed and very welcome review by G. E. Hutchinson on "The biochemistry of the

here interested in the case in which $p_o = p_w$ and, provided $\Delta\theta$ is not too large, we may put

$$p_s = p_i + \Delta\theta \frac{\partial p_i}{\partial \theta}$$

where p_i is the saturation vapour pressure over ice at temperature θ. We then easily obtain from equations (5) and (6)

$$a\frac{da}{dt} = \frac{GMDk\,(p_w - p_i)}{\sigma(R\theta k + D\lambda\, \partial p_i/\partial\theta)} \qquad \ldots\ldots (7)$$

to represent the rate of growth of a single particle.

Condition for maintenance of water saturation.—In order that water saturation may be just maintained we must have

$$4\pi n\sigma a^2 \frac{da}{dt} = -\frac{d\rho w}{dt},$$

where n is the number of ice particles per cubic centimetre. Substituting for da/dt and $d\rho_w/dt$ from equations (7) and (1) respectively we obtain

$$V = B\frac{Gan}{\Gamma_s}, \qquad \ldots\ldots (8)$$

where

$$B = \frac{4\pi kDR\theta\,(p_w - p_i)}{(\partial p_w/\partial\theta - p_w/\theta)\,(R\theta k + D\lambda\, \partial p_i/\partial\theta)}. \qquad \ldots\ldots (9)$$

In order to assess the minimum value of V necessary to maintain liquid water in the cloud we must evaluate the five variables of which V is a function.

Evaluation of B.—The quantity we have denoted by B is a function of temperature. Inserting appropriate numerical values for various parameters (c.g.s. units) we find the following values.

θ(°A.)	273	268	263	258	253	248	243
B	0	1·0	2·2	3·3	4·3	5·1	5·7

Evaluation of Γ_s.—The temperature lapse rate in the cloud is a function of height and temperature but a reasonable approximation to the saturated lapse rate is given by taking $\Gamma_s = 7 \times 10^{-5}$ °C. cm.$^{-1}$.

Evaluation of a.—The evaluation of a, the radius of the equivalent spherical ice particle, is somewhat more difficult. As a preliminary step it is useful to consider the rate of growth indicated by equation (7) and with the assumption that G is unity. If S is the surface area of the ice sphere

$$\frac{dS}{dt} = 8\pi a \frac{da}{dt}$$

$$= \frac{8\pi GMDk\,(p_w - p_i)}{\sigma(R\theta k + D\lambda\partial p_i/\partial\theta)}.$$

Thus dS/dt is a function only of temperature. Inserting appropriate values for the parameters involved and putting $\sigma = 0{\cdot}9$ and $G = 1$ we get

θ	268	263	258	253	248	243
dS/dt	$5{\cdot}6\times10^{-7}$	$8{\cdot}5\times10^{-7}$	$9{\cdot}2\times10^{-7}$	$8{\cdot}4\times10^{-7}$	$7{\cdot}0\times10^{-7}$	$5{\cdot}2\times10^{-7}$

in c.g.s. units. The variation with temperature is thus small and to a close approximation we can put $dS/dt = 8 \times 10^{-7}$ and $S = 8 \times 10^{-7}t$ to give a

reasonable approximation to the size of the particle t sec. after it is first formed in an atmosphere saturated with respect to liquid water. From this formula we easily obtain the following values for the radius of the equivalent spherical ice particle

t (sec.)	10	100	1,000	10,000
a (μ)	8	25	80	250

The radius varies as the square root of the time and it is apparent that a reaches a value between 50 and 100 μ within minutes but that hours are necessary for the particle to grow to significantly greater sizes. We shall see below that G is of the order 2·3 so that the assumption of unity for G has led to an underestimation of a by a factor of less than 1·5. Weickmann[3] has provided a number of photographs of ice crystals caught in cirrus cloud. Many of these crystals were in the form of plates or prisms and photographs of 17 were measured and the radius of the sphere of similar surface area computed assuming the prisms to be cylinders and the plates to be discs. For the prisms the resulting value of a was about 80 μ at 233°A. and about 160 μ at 263°A. The plates occurred only at the higher temperatures of course and gave a mean value of about 250 μ for a at 263°A. These values are in agreement with the values to be expected (as regards order of magnitude) from consideration of the rate of growth and we may conclude that a is likely to be between 50 μ and 300 μ.

Evaluation of G.—The best known formula for G is probably that of Frossling[4] who suggested

$$G = 1 + 0{\cdot}23(R_e)^{\frac{1}{2}},$$

where R_e is the Reynolds number of the falling particle. Frossling's result[4] was based upon the evaporation of spherical drops of water. The present writer[5], from a consideration of work including heat transfer as well as vapour transfer, has suggested

$$G = 1 + 0{\cdot}14(R_e)^{0{\cdot}6}.$$

In view of the accuracy with which we can work in the present problem the difference is not significant. For both formulae we must evaluate R_e.

Nakaya[6] quotes the average size of plate crystals as 0·8 mm. and prism crystals as 0·5 mm. The terminal velocities of crystals are not known in detail, but on the basis of the terminal velocities quoted by Nakaya for other types of crystal it seems likely that they are less than 60 cm. sec.$^{-1}$ for the plate and 100 cm. sec.$^{-1}$ for the prism. Taking the kinematic viscosity of air as 0·12 c.g.s. units these figures lead to values of 40 and 42 for the Reynolds number for plate and prism respectively. Whichever formula is used for G we then get a value of about 2·3. The values of a tabulated as a function of time in the preceding section were based upon a value of unity for G. The actual value varies with the crystal size but since $G \simeq 2{\cdot}3$ for the average crystal and since a varies as $\sqrt{G}$ the factor by which the tabulated values are in error is probably less than 1·5.

Evaluation of n.—This is the most difficult parameter to assess. The work of Findeisen and Shulz[7] suggests that the initial formation of ice crystals in rising air may be at the rate of about one per cubic metre at 263°A. and 1 per litre at 243°A. If this is so we should put $n = 10^{-6}$ at 263°A. and $n = 10^{-3}$ at 243°A. Subsequently of course more crystals may be produced by the splintering process and this may be the dominant factor in the later stages of the life of the cloud.

terrestrial atmosphere" completes the section devoted to the bulk of the atmosphere. There follow authoritative articles on the absorption and emission spectra of the atmosphere, density, pressure and temperature above 30 Km., and the physics and photochemistry of the outer layers. The great disappointment of the book comes with the chapter "Dynamic effects in the high atmosphere" by M. Nicolet. Nicolet's very distinguished work has been concerned with the fashionable outer fringe, indeed it has done much to set the fashion, and he interprets his title in the light of his own special interest. The chapter comprises a discussion of hydrostatics, gas kinetics, and the inevitable speculative photochemistry, but little or no dynamics. Nicolet says "The motions in the high atmosphere cannot be studied as in meteorology, where the Coriolis force is dominant". This statement deserves, though it does not receive, justification; the more so since the lower atmosphere for the purposes of the book as a whole appears to end at 30 Km., with the implication that the high atmosphere begins there. There is no discussion, worthy of the rest of the book, of upper atmospheric motions, tidal or otherwise.

I would not like to end a notice of such an excellent book in critical fashion, and the last two short chapters give ample scope for enthusiasm. I was glad to see a description of Danjon's remarkable observations in a place where meteorologists are likely to read it, but cannot say I found it easy to follow. There is a use of the word "hence" near the top of p. 733 which is worthy of the attention of a future Fowler. The section to which I have turned repeatedly is however that by C. T. Holliday "The earth as seen from outside the atmosphere" which contains eight pictures of the south-west United States, taken from elevations of about 100 Km., excellently reproduced. The meteorological possibilities opened up by the use of even so simple an instrument as a camera at these levels are clearly enormous. I specially commend to your attention Fig. 5, in which you ". . . note shadows of cirrus clouds on Pacific sea fog. Nearer, thunderheads are forming over mountain ranges, with cloud streets prominent near all mountains. . . .". The day is clearly not far distant when someone will publish a photograph of a mature extratropical cyclone, and it is surely not unlikely that such a photograph will repay careful scrutiny.

G. D. ROBINSON

METEOROLOGICAL OFFICE NEWS

Retirements.—*Cmdr M. Cresswell, R.N.R.*, who has been Port Meteorological Officer at Liverpool for nearly 32 years, retired on June 26, 1956. Despite his retirement he is not severing contact with the Meteorological Office; in August 1956 he takes over the duties of Merchant Navy Agent in the Humber area in succession to Capt. R. E. Dunn who is retiring from that agency. (A Merchant Navy Agent carries out similar duties to a Port Meteorological Officer but, instead of being a full-time employee of the Meteorological Office, he is paid on a "fee" basis).

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ERRATUM

JULY 1956, PAGE 205. Table I. No breaks within 12 hr., Mean; *for* "28" *read* "18".

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The features of this period dominated the mean-pressure map for the month. The normal weak polar anticyclone was displaced to Spitsbergen and was more intense than normal, the pressure anomaly there being of the order of + 7 mb. The area of positive pressure anomaly extended to Iceland (+ 2 mb.) where the mean-pressure map did not show the normal low-pressure area. Pressure was also above normal over most of Canada (anomaly + 5 mb. in the North-West Territories) and a little above normal in the Rocky Mountains area of the United States. From the Azores across Great Britain to Denmark, pressures were 1 mb. or 2 mb. below normal. Zonal flow in the America–Atlantic–United Kingdom Sector was thus weaker than normal.

Temperature was near normal over much of the hemisphere, the major anomalies being $-1°$ C. to $-2°$C. in east Germany and the Baltic and in the Great Lakes area of America, and $+1°$C. to $+2°$C. in the eastern Mediterranean and in the Rockies.

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terrestrial atmosphere" completes the section devoted to the bulk of the atmosphere. There follow authoritative articles on the absorption and emission spectra of the atmosphere, density, pressure and temperature above 30 Km., and the physics and photochemistry of the outer layers. The great disappointment of the book comes with the chapter "Dynamic effects in the high atmosphere" by M. Nicolet. Nicolet's very distinguished work has been concerned with the fashionable outer fringe, indeed it has done much to set the fashion, and he interprets his title in the light of his own special interest. The chapter comprises a discussion of hydrostatics, gas kinetics, and the inevitable speculative photochemistry, but little or no dynamics. Nicolet says "The motions in the high atmosphere cannot be studied as in meteorology, where the Coriolis force is dominant". This statement deserves, though it does not receive, justification; the more so since the lower atmosphere for the purposes of the book as a whole appears to end at 30 Km., with the implication that the high atmosphere begins there. There is no discussion, worthy of the rest of the book, of upper atmospheric motions, tidal or otherwise.

I would not like to end a notice of such an excellent book in critical fashion, and the last two short chapters give ample scope for enthusiasm. I was glad to see a description of Danjon's remarkable observations in a place where meteorologists are likely to read it, but cannot say I found it easy to follow. There is a use of the word "hence" near the top of p. 733 which is worthy of the attention of a future Fowler. The section to which I have turned repeatedly is however that by C. T. Holliday "The earth as seen from outside the atmosphere" which contains eight pictures of the south-west United States, taken from elevations of about 100 Km., excellently reproduced. The meteorological possibilities opened up by the use of even so simple an instrument as a camera at these levels are clearly enormous. I specially commend to your attention Fig. 5, in which you ". . . note shadows of cirrus clouds on Pacific sea fog. Nearer, thunderheads are forming over mountain ranges, with cloud streets prominent near all mountains. . . .". The day is clearly not far distant when someone will publish a photograph of a mature extratropical cyclone, and it is surely not unlikely that such a photograph will repay careful scrutiny.

G. D. ROBINSON

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In the British Isles July was generally changeable and unsettled with thundery rains, except during the fourth week when the weather was largely dominated by an anticyclone, which moved north-east from the Azores.

A vigorous depression over Ireland on the 1st gave cool showery weather over most of the British Isles with thunderstorms in many places during the first two or three days of the month as it moved slowly north. Widespread rain on the 4th and 5th was associated with the passage north-east across the country of a complex depression from the Atlantic; the thundery tendency continued and rain was heavy locally; 3·12 in. fell in 24 hr. at Blaenau Festiniog on the 4th. A ridge of high pressure which followed the depression gave a fine day on the 6th with over 12 hr. sunshine at many places, but warm moist air brought extensive fog to the English Channel and Irish Sea during the next two days and raised temperatures inland to about 80°F. Thunderstorms broke out over a wide area on the night of the 8th—9th. Several places in the Home Counties recorded over 2 in. of rain during 24 hr.; a 'remarkable' fall of 1¼ in. in 30 min. was recorded at Sutton, Surrey, while the 2·38 in. measured in 12 hr. at Kew Observatory was the most in a rainfall day since records began there in 1871. Three sunny but cooler days, with local ground frost early, followed the thunderstorms as a shallow anticyclone moved northward over the country. Pressure was highest to the north of the British Isles and winds over the country were mainly from an easterly direction from the 12th to the 20th. On the 13th and 14th rain from the North Sea brought temperatures below their seasonal normal but thereafter weather improved slowly and Scotland and parts of northern England had several warm sunny days. Thunderstorms developed widely again from the 16th to the 19th as a depression off western Ireland moved south-east to the Bay of Biscay and northern France. Storms were particularly heavy on the 18th and 19th and there were many noteworthy falls with considerable flooding; on the 18th 3·71 in. was recorded at St. Ives, Huntingdonshire in 24 hr. and a 'very rare' fall occurred at Harmondsworth, Middlesex when 3·87 in. fell in 114 min., on the 19th. 3·21 in. fell at Liskeard, Cornwall in 24 hr. and there was a 'remarkable' fall of 1·29 in. in 30 min, at Beer, Devon. On the 21st the easterly winds were replaced by a weak westerly flow. The northern parts of the British Isles had slight rain from time to time, but with the approach of an anticyclone from the Azores warm sunny weather spread from the south with temperature exceeding 80°F. in places. On the 27th temperature reached 86°F. at Jersey and 83°F. at Tunbridge Wells, Kent. Early on the 29th a deepening depression from the Atlantic became exceptionally vigorous for the time of year as it approached south-west England. Central pressure fell to 976 mb. equalling the lowest previously recorded during July in the British Isles—at Tynemouth in 1922. Gales were widespread and severe in places over the southern half of England and Wales and rain heavy locally. In Cornwall wind reached 76 kt. in gusts at St. Mawgan and 57 kt. at Culdrose. The previous highest gust in the British Isles during July was 64 kt. at Lympne, Kent in 1938; gusts of more than 55 kt. during this month are rare. Damage during the gales was considerable. Eleven people are reported to have been killed, six by falling trees. The London–Holyhead road was blocked by a landslide in the Nant Francon Pass, Caernarvonshire and among the many tragedies at sea was the capsizing of the *Teeswood* (1,246 tons) off Dungeness, Kent, and the sinking of the sail-training ship *Moyana* off the Lizard. The following day was showery with considerable sunny periods in the south but with heavy rain in Scotland. Brighter but cooler weather extended to most of the British Isles by the 31st.

The outstanding feature of the month was the high rainfall. New rainfall records for July were set up at Pembroke Dock, Valley, Dishforth, Stornoway and Kew. Kew had over an inch more than their previous highest (in 100 yr. of readings) of 4·88 in. in 1880. Sunshine was below average particularly in south-east England and temperature over the month was about average although day maxima were rather below normal.

The violent storms and gales have caused considerable damage to crops. Reports of flooding and damage to grain, particularly barley, have been received, but it is hoped that most of it will still be harvested. Cattle and sheep were killed during heavy thunderstorms in Hereford. The gales of the 29th caused widespread damage over the whole country, and among many reports are some from Kent of top fruit blown down and havoc in the hop fields.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ..	86	33	−0·8	137	+1	87
Scotland	79	31	−0·8	160	0	100
Northern Ireland ...	73	38	−0·2	132	+1	100

RAINFALL OF JULY 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square	5·90	248	*Glam.*	Cardiff, Penylan	2·82	92
Kent	Dover	2·76	131	*Pemb.*	Tenby	4·14	140
,,	Edenbridge, Falconhurst	3·37	146	*Radnor*	Tyrmynydd	4·04	98
Sussex	Compton, Compton Ho.	3·21	113	*Mont.*	Lake Vyrnwy	8·06	226
,,	Worthing, Beach Ho. Pk.	2·74	134	*Mer.*	Blaenau Festiniog	12·11	142
Hants.	St. Catherine's L'thouse	1·66	85	,,	Aberdovey	5·48	157
,,	Southampton (East Pk.)	2·26	99	*Carn.*	Llandudno	3·96	177
,,	South Farnborough	3·12	153	*Angl.*	Llanerchymedd	5·67	198
Herts.	Harpenden, Rothamsted	2·43	106	*I. Man*	Douglas, Borough Cem.	4·25	139
Bucks.	Slough, Upton	3·45	180	*Wigtown*	Newton Stewart	5·43	173
Oxford	Oxford, Radcliffe	2·43	103	*Dumf.*	Dumfries, Crichton R.I.	5·95	182
N'hants.	Wellingboro' Swanspool	4·33	189	,,	Eskdalemuir Obsy.	6·83	167
Essex	Southend, W. W.	3·02	152	*Roxb.*	Crailing	3·67	127
Suffolk	Felixstowe	2·38	122	*Peebles*	Stobo Castle	4·53	156
,,	Lowestoft Sec. School	1·78	78	*Berwick*	Marchmont House	3·54	116
,,	Bury St. Ed., Westley H.	1·72	69	*E. Loth.*	North Berwick Gas Wks.	4·87	189
Norfolk	Sandringham Ho. Gdns.	3·03	118	*Midl'n.*	Edinburgh, Blackf'd. H.	5·21	185
Wilts.	Aldbourne	2·96	117	*Lanark*	Hamilton W. W., T'nhill	4·94	172
Dorset	Creech Grange	4·67	190	*Ayr*	Prestwick	4·05	165
,,	Beaminster, East St.	2·77	107	,,	Glen Afton, Ayr San.	5·86	140
Devon	Teignmouth, Den Gdns.	2·56	110	*Renfrew*	Greenock, Prospect Hill	4·89	132
,,	Ilfracombe	4·33	170	*Bute*	Rothesay, Ardencraig	..	..
,,	Princetown	7·99	149	*Argyll*	Morven, Drimnin	7·84	178
Cornwall	Bude, School House	..	..	,,	Poltalloch	6·27	152
,,	Penzance	5·07	186	,,	Inveraray Castle	6·92	139
,,	St. Austell	4·32	129	,,	Islay, Eallabus	3·90	114
,,	Scilly, Tresco Abbey	3·87	174	,,	Tiree	4·12	114
Somerset	Taunton	2·18	103	*Kinross*	Loch Leven Sluice	4·52	157
Glos.	Cirencester	3·06	115	*Fife*	Leuchars Airfield	3·91	150
Salop	Church Stretton	2·84	108	*Perth*	Loch Dhu	7·26	150
	Shrewsbury, Monkmore	3·28	156	,,	Crieff, Strathearn Hyd.	5·00	168
Worcs.	Malvern, Free Library	2·69	118	,,	Pitlochry, Fincastle	4·26	158
Warwick	Birmingham, Edgbaston	3·83	150	*Angus*	Montrose, Sunnyside	3·64	138
Leics.	Thornton Reservoir	2·53	102	*Aberd.*	Braemar	2·99	116
Lincs.	Boston, Skirbeck	2·62	119	,,	Dyce, Craibstone	5·76	190
,,	Skegness, Marine Gdns.	2·62	120	,,	New Deer School House	4·89	160
Notts.	Mansfield, Carr Bank	3·00	115	*Moray*	Gordon Castle	5·29	165
Derby	Buxton, Terrace Slopes	6·13	156	*Nairn*	Nairn, Achareidh	4·66	183
Ches.	Bidston Observatory	4·71	182	*Inverness*	Loch Ness, Garthbeg	7·25	229
,,	Manchester, Ringway	4·45	160	,,	Loch Hourn, Kinlochourn	9·89	156
Lancs.	Stonyhurst College	5·96	154	,,	Fort William, Teviot	5·57	114
,,	Squires Gate	4·70	169	,,	Skye, Broadford	7·77	140
Yorks.	Wakefield, Clarence Pk.	4·40	174	,,	Skye, Duntulm	6·26	167
,,	Hull, Pearson Park	3·66	156	*R. & C.*	Tain, Mayfield	5·90	216
,,	Felixkirk, Mt. St. John	4·91	180	,,	Inverbroom, Glackour	7·55	203
,,	York Museum	3·63	144	,,	Achnashellach	6·87	141
,,	Scarborough	3·40	140	*Suth.*	Lochinver, Bank Ho.	6·34	209
,,	Middlesbrough	2·37	93	*Caith.*	Wick Airfield	3·62	138
,,	Baldersdale, Hury Res.	3·46	119	*Shetland*	Lerwick Observatory	3·85	168
Norl'd.	Newcastle, Leazes Pk.	2·56	100	*Ferm.*	Crom Castle	5·79	166
,,	Bellingham, High Green	2·86	87	*Armagh*	Armagh Observatory	3·81	132
,,	Lilburn Tower Gdns.	3·32	134	*Down*	Seaforde	3·12	98
Cumb.	Geltsdale	3·43	99	*Antrim*	Aldergrove Airfield	2·44	87
,,	Keswick, High Hill	7·23	188	,,	Ballymena, Harryville	4·47	130
,,	Ravenglass, The Grove	5·10	136	*L'derry*	Garvagh, Moneydig	5·57	172
Mon.	A'gavenny, Plâs Derwen	3·68	135	,,	Londonderry, Creggan	4·56	124
Glam.	Ystalyfera, Wern House	5·57	122	*Tyrone*	Omagh, Edenfel	5·05	149

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·82	92
·14	140
·04	98
·06	226
·11	142
48	157
96	177
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